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DSTO

A Data Screening Technique for AFDAS

L. Molent, K. Walker and R. Ogden

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Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

This report presents the details of a technique which was adapted to correlate two individual Aircraft Fatigue Data Analysis System (AFDAS) data channels, or other data presented as range mean pairs, as a method of data screening or validation. Although the technique is here-in demonstrated by using operational RAAF F/A-18 AFDAS data, the approach is not aircraft type dependent, and is intended for general AFDAS (or any range mean pair) data screening purposes. A PC based program developed to implement the screening process is also described.

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Fax: (03) 9626 7999

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EXECUTIVE SUMMARY

The safe and economical operation of the RAAF's aircraft fleet throughout its life cycle is an essential requirement for the Australian Defence Force. To assist the fleet manager in attaining these goals a number of fatigue life monitoring tools and systems have been established by the RAAF. Most RAAF aircraft contain on-board fatigue monitoring devices ranging from the relatively simple "counting accelerometers" through to near-real time flight parameter recorders.

One fatigue monitoring tool common to a large number of aircraft type in the RAAF inventory (F/A-18, F-111C, Macchi and PC-9) is the DSTO pioneered Aircraft Fatigue Data Analysis System (AFDAS). The AFDAS is an electronic device which pairs turning points (ie maxima and minima) in time histories of strain or acceleration according to a range-mean-pair (RMP) counting algorithm, and stores the counts in an array. The RMP method is generally deemed one of the most appropriate means of presenting fatigue usage data. As the AFDAS compresses usage data in this form, little post-processing is required to obtain useful usage data.

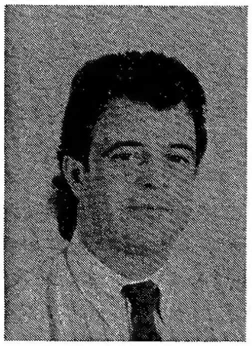
Although there exists within the AFDAS a self-check capability, this is limited to hardware faults and gross errors of the recorded RMP structure. This capability is very useful, yet in its self, does not guarantee the integrity of the accumulated data. For this reason additional interrogation, using suitable criteria, is required before data integrity is assured and mature AFDAS utilisation can proceed.

This report presents the details of a modification to a technique developed originally by *Howard* of DSTO to correlate two individual AFDAS data channels, as a method of data screening or validation. This technique essentially compares the distributions of two related RMP tables and produces a linear regression factor. Although the technique is demonstrated here by using operational F/A-18 AFDAS data, the approach is not aircraft type dependent, and is intended for general AFDAS (or any RMP) data screening purposes. In order to use this technique, transfer functions between several combinations of AFDAS location were also derived.

The AFDAS has the potential to be a powerful fatigue life management tool. Once data integrity can be routinely assured, fatigue damage assessment may be possible, even at the individual aircraft squadron level.

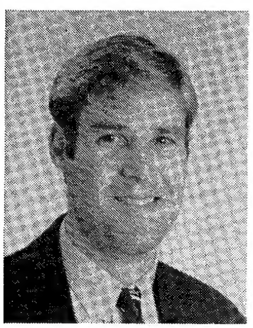
Authors

L. Molent
Airframes and Engines Division



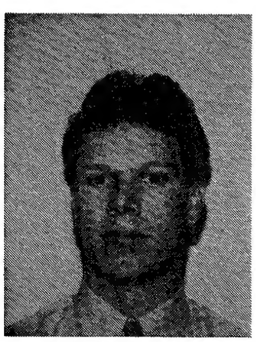
Mr Molent graduated in 1983 with a Bachelor of Engineering (Aeronautical). Since commencing employment at the then Aeronautical Research Laboratories in 1984, Mr Molent has worked in the fields of aircraft structural integrity, structural and fatigue testing, aircraft accident investigation and aircraft vulnerability. He has numerous publications in these technical areas. He has been attached to both the Civil Aviation Department (1985) and the US Navy (NAVAIR, 1990 - 1991) as an airworthiness engineer. Mr Molent is currently task manager F/A-18 life assessment, at the Aeronautical and Maritime Research Laboratory.

K. Walker
Airframes and Engines Division



Mr Walker graduated in 1983 with a Bachelor of Aeronautical Engineering (with distinction) from RMIT. He then served for eight years with the RAAF, including a posting to the USA where he gained a Masters of Science in Aeronautics and Astronautics from Purdue University. He then worked for three years in private industry before joining AMRL in early 1994. His work at AMRL has included fatigue and damage tolerance analysis studies and aircraft load spectrum determination using the Aircraft Fatigue Data Analysis System (AFDAS). He is currently also task manager "Analysis and Validation of Design Procedures for Bonded Repairs"

R.W.Ogden
Airframes and Engines Division



Mr. Ogden graduated from RMIT in 1992 with a Bachelor of Engineering honours degree in Aerospace Engineering. Since commencing employment as a contract engineer at the then Aeronautical Research Laboratory in 1993 and subsequently as a permenant engineer in 1995, Mr. Ogden has been working in the area of aircraft structural integrity, dealing specifically with the Aircraft Fatigue Data Analysis System (AFDAS), and also in the analytical calibration of on board fatigue sensors.

Contents

1. Introduction

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Although there exists within the AFDAS a self-check capability, this is limited to hardware faults and gross errors of the recorded RMP structure. This capability is very useful, yet in its self, does not guarantee the integrity of the accumulated data. For this reason additional interrogation, using suitable criteria, is required before data integrity is assured and mature AFDAS utilisation can proceed.

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The AFDAS has the potential to be a powerful fatigue life management tool. Once data integrity can be routinely assured, fatigue damage assessment may be possible, even at the individual aircraft squadron level.

2. AFDAS

The AFDAS was invented by Australia's DSTO Aeronautical Research Laboratory (ARL[1]) and was developed commercially and is currently marketed by British Aerospace Australia Limited. The AFDAS directly monitors and counts relevant fatigue strain cycles occurring at selected locations on the aircraft structure. Central to the AFDAS is an airborne unit referred to as the Strain Range Pair Counter (SRPC), which automatically processes and stores (a "*data base*") the information from the sensors. Fresh data is added to the data base each time the aircraft flies. This data can then be transferred to a useable media (eg. *floppy disc*) by means of a portable data readout computer. Software would then be available to interrogate this data to provide additional fleet management capability. The SRPC monitors the output of the sensors during the flight load-time waveform, and pairs and extracts the maxima and minima, which are known as "RMP", which then form the basis of subsequent fatigue analyses. As no time correlation is retained, the principle that fatigue damage is independent of the rate of change of stress and time sequencing of cycles is thus inherent.

2.1 Range Pairs

This method of load cycle counting, assumes that fatigue damage produced by a sequence of loads is dependent upon the magnitude of stress at turning points regardless of where they occur in a sequence Ref 2, and is widely accepted as suitable in identifying cycles for the purpose of cumulative damage analyses. In effect, maxima and minima are paired to form cycles in such a way that each cycle produces the same damage as would a cycle of the same amplitude and mean value in a constant amplitude fatigue test. Thus constant amplitude fatigue data along with an appropriate damage theory, can be used to assess damage due to a random load history.

The process of converting a load-time history to range pairs can be regarded as a successive extraction and smoothing process, see Ref 2. Here, the smallest perturbation is found first, the values of the two turning points are noted as the first range pair, and the perturbation replaced by a smooth curve. This process is repeated until all turning points[2] are accounted for. A range pair cycle is deemed to have occurred when its maximum and minimum are contained within other maxima and minima of at least the same magnitude. Only those turning points which are greater than a specified quantisation level are kept and recorded in terms of counts of maxima and minima. In the AFDAS, the magnitude of the ranges are quantised into a number of bands. The number of bands is currently set at 16. The process of detecting and counting range pair cycles is performed continuously in real time. This significantly reduces the amount of subsequent processing required. Further range pair and AFDAS details are given in Ref 2 and 3.

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[1] Now the Aeronautical and Maritime Research Laboratory (AMRL)

[2] Note, the value and slope of the last unmatched TP is stored by AFDAS and applied to the next set of flight data.

2.2 Channel Ranges

In the case of the RAAF F/A-18 aircraft the location of the strain sensors, which were chosen for their fatigue criticality, are presented in Table 1.

The F/A-18 AFDAS (currently Mark 3 - Mk3) strain ranges have been pre-set based on the expected maximum and minimum strain at each AFDAS location as derived analytically by the aircraft's manufacturer McDonnell Douglas Aircraft Company (MDA), see Table 2.

Table 1: RAAF F/A-18 AFDAS Locations

Channel No.	Descriptor (RAAF)	Location
0	FS453	Y453 Bulkhead (inboard of Left Hand (LH) wing attachment)
1	FS470	Y470 Bulkhead (inboard of LH wing attachment)
2	FS488	Y488 Bulkhead (inboard of LH wing attachment)
3	RHWF	RH Outer Mould Line (OML) Skin at the Wing Fold (WF)
4	RHWR	Right Hand (RH) Wing Root (WR) Lower Lug at Y470.5
5	FF	RH Forward Fuselage (FF) Canopy Sill at Y213
6	FS645HT	RH Horizontal Tail (HT) Spindle Support Frame at Y645
7	FS657HT	RH HT Spindle Support Frame at Y657
8	FS566VT	RH VT Attachment Stub at Y566
9	FS598VT	RH Vertical Tail (VT) Attachment Stub at Y598
10	WTEF	RH Wing Trailing Edge Flap Actuator
11	N_z	Normal Acceleration

Table 2 : RAAF F/A-18 Estimated AFDAS Strain Ranges

No	MATERIAL	PREDICTED STRAIN RANGE			
		MAXIMUM		MINIMUM	
		με	CONDITION**	με	CONDITION
			Manoeuvre, Mach, Alt (kft), g		Manoeuvre, Mach, Alt (kft), g
0	7050-T73651 Al. Plate	1250	SSPD,0.8,SL,-2.25	-3300	SSPU,0.8,SL,9.25
1	7050-T73651 Al. Plate	600	SSPD,0.8,SL,-2.25	-1600	SSPU,0.8,SL,9.25
2	7050-T73651 Al. Plate	900	SSPD,0.8,SL,-2.25	-2250	SSPU,0.8,SL,9.25
3	Carbon/Epoxy Comp.	1200	SSPU,0.8,SL,7.5	-700	SSPD,0.9,SL,-3.0
4	6AL-4V Titanium	2100	SSPU,0.8,SL,9.25	-650	SSPD,0.9,SL,-3.0
5	7050-T7351 Al. Plate	1600	SSPU,V_L*,SL,7.5	-550	OFF CENT. CAT
6	6AL-4V Titanium	1550	roll 360°,V_L, SL, 1.0	-1200	RPO,0.93,5,6.0
7	6AL-4V Titanium	1400	roll 360°,V_L, SL, 1.0	-1900	RPO,0.93,5,6.0
8	7050-T73652 Al. Forg.	2200	RPO,0.7,5,6.0	-2200	SSPD,V_H,SL,-3.0
9	7050-T73652 Al. Forg.	1700	RPO,0.7,5,6.0	-1700	SSPD,V_H♦,SL,-3.
10	6AL-4V Titanium	2650	roll 360°,0.95, 20, 1.0	-3300	SSPU,0.54,SL,7.5
11	N_z (g)	10	-	-10	-

* ♦ V_L = V_H = limit speed

** Condition leading to predicted strain

From the analysis conducted in Ref 4, which was based on flight trials data, it was concluded that these ranges were not optimum and thus new ranges were recommended. As noted in Ref 4, data for two AFDAS sensors was unavailable from the IFOSTP/ARDU flight data, and thus new ranges for these were based on other data sources. Subsequently, more flight data (referred to as ARDU phase II) was obtained which included the previously missing sensors. (For completeness, the recommended ranges for all the AFDAS sensors are presented in Appendix 1. The methods described in Ref 4 were used here to produced the complete list.)

Modification of F/A-18 AFDAS is planned for mid 1995 to incorporate the optimal ranges. As the data used in this report was collected from unmodified AFDAS units, the ranges presented in Table 2 were used in the subsequent sections.

3. Correlation Procedure

AFDAS processing software developed by Hawker de Havilland Victoria Limited Ref 5, which interrogates data extracted from the SRPC includes routines to screen the data for potential errors including the following:

a. Documentary data discrepancies including invalid tail number and dates/times.

b. Errors in the hardware including amplifier errors, battery voltage level low and strain gauge errors.

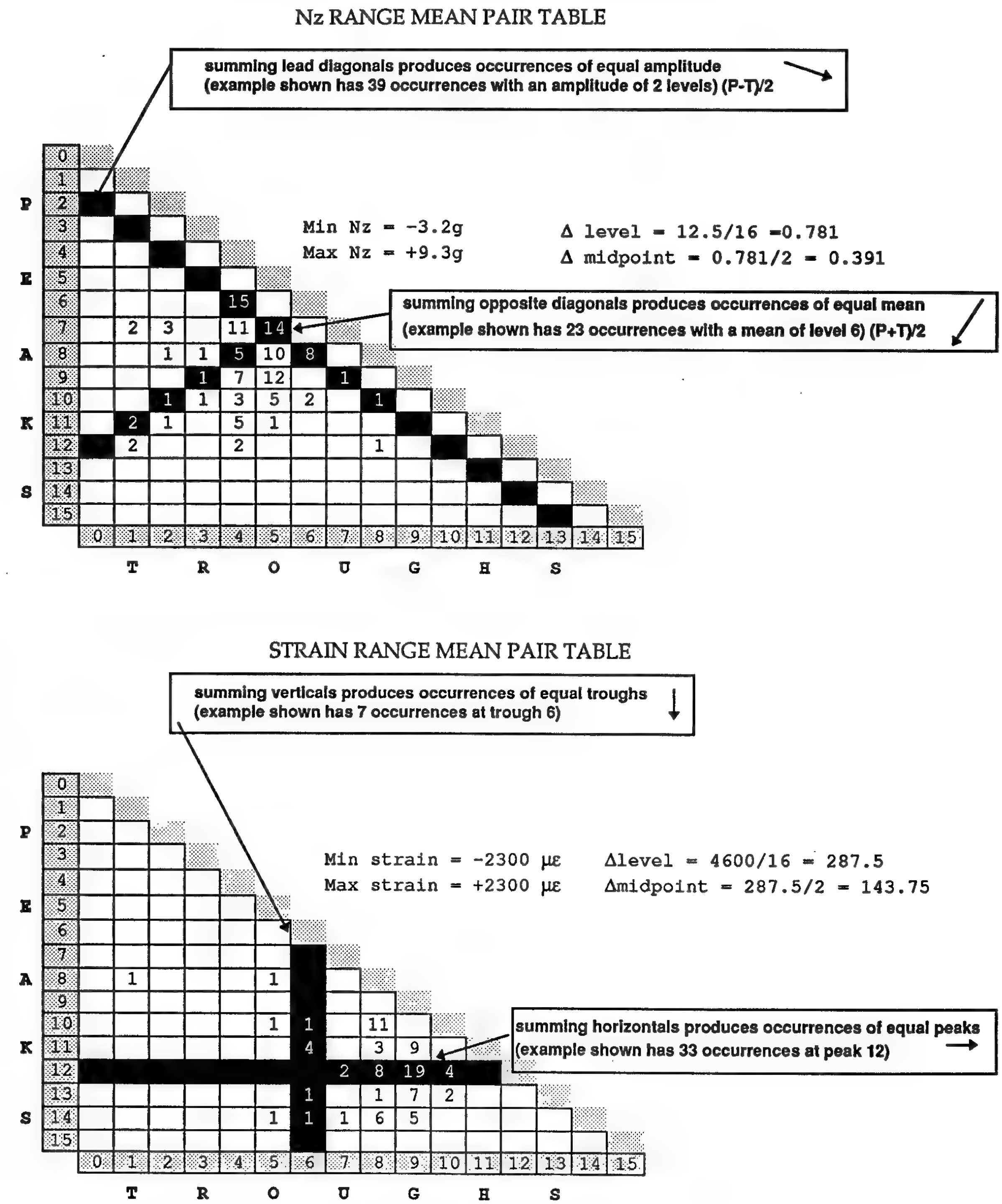
c. Checking the range pair data outputs providing warnings if there are counts in the extreme windows, if there is an invalid range pair data structure (trough higher than a peak), or if the counts in any window exceed a certain predetermined value.

The data screening as described above is useful and necessary, but is very limited. The checks described in sub paragraph (c) above are defined based on expected theoretical outputs for a particular channel. For example, if the strain ranges have been properly set, counts would not be expected in the extreme windows. However, a method of checking the correlation of separate channels on the system both internally and against some expected value was identified as being required. A method which could be readily incorporated into a computer program would be the most practical solution.

The screening method utilised in this report is based on the work of Howard, Ref 1, which:

- details several potential methods of correlating two channels from AFDAS when the data is presented in the form of two RMP tables. The primary method is based on comparing the frequency distributions from two different sources to check for correlation. For example, good correlation would be expected between the vertical acceleration channel (N_Z) and a strain channel which is primarily driven by N_Z (See Section 4). In the Ref 1 report, data from the Mirage aircraft was used, and a comparison was made between the N_Z channel and a strain gauge located on the wing main spar tension flange. Very good correlation results were obtained.

[A check of the N_Z RMP table against the fatigue meter data is also possible by running the range pair data through a fatigue meter logic algorithm, but this is not pursued here.]



* recall that there are 16 bands currently set for AFDAS

Figure 1: Mirage RMP Tables for Nz and Strain

- correlations were performed by comparing four distributions obtained from the RMP tables; amplitudes, means, peaks and troughs. Summing the occurrences along the diagonals parallel to the leading diagonal produces the amplitude distribution, summing along the opposite diagonals produces the mean distribution, summing vertically produces the peak distribution and summing horizontally produces the trough distribution. A slight modification of the method was applied to the individual distributions. The RMP tables for the N_Z and strain data from Ref 1 and a demonstration of the summing procedure is shown in Figure 1.

- the correlation technique is based on the notion that even though a one to one relationship between the load (N_z) and strain ($\mu\varepsilon$) events cannot be extracted from the AFDAS strain range pair tables, the exceedence distributions of the two parameters should be similar. By comparing the two distributions, it is possible to determine if a linear relationship (as expected) exists between the two.

- involved manual plotting and correlating to produce a final strain per *g* value.

An interpretation of these concepts has been used in a simplified procedure as described in the following section. This procedure was designed to be automated so that it could be incorporated in a computer based screening system.

3.1 Simplified Correlation Procedure

Details of a simplified and automated correlation procedure, which was based on the Ref 1 technique, are as follows:

(Steps (a) to (d) are shown in Table 3A, using the Ref 1 data shown in Figure 1.)

a. Sum the lead diagonals, opposite diagonals, horizontals and verticals of the two RMP tables of interest, to produce occurrence distributions based on amplitudes, means, peaks and troughs.

b. At each level from (a), produce cumulative sums up to and including that level.

c. At each level express the occurrence for that level as a percentage of the total.

d. Working in order of increasing Nz/strain, determine the mid point between the cumulative occurrence percentages at each Nz/strain. For each Nz/strain level there is therefore one unique cumulative occurrence mid point percentage.

e. Construct a table linking the cumulative mid point percentages with the load/strain levels from the two RMP tables, performing linear interpolation as necessary to obtain one or other of the quantities (Table 3B).

f. Plot the load/strain values obtained from (d) against each other on a linear scale and fit a straight line to the result. The slope of this line is the quantity of interest, for example strain per *g* (same as strain per N_Z), see Figure 2.

A complicating factor in the above procedure relates to the way the two channels to be correlated are expected to behave. Where they are expected to act in the same sense, ie an increase in one is expected to correlate with an increase in the other, the procedure is performed exactly as discussed. If the converse is true, then the RMP table must first be transposed before performing the comparison. The transposition effectively swaps the peaks and troughs. Where the channels operate in the same sense a peak in one relates to a peak in the other, and a trough relates to a trough. Where the two channels operate in opposite senses a peak in one relates to a trough on the other, so a transposition is required to one channel to allow a valid comparison to be performed. (This was not considered in Ref 1).

A similar exercise was performed for the other three distributions and the results are presented in Ref 6.

Table 3A: Strain vs Load Results Based on Amplitude Distributions from Ref 1 Data (Figure 1)

Nz RMP DATA			STRAIN RMP DATA		
Nz Amplitude "g" (step d)	**Occurrences (steps a,b)**	**Cumulative Occurrences Mid-point % (step c)**	**Strain Amplitude "με" (step d)**	**Occurrences (steps a,b)**	**Cumulative Occurrences Mid -point % (step c)**
0.391	39	16.53	143.75	24	13.48
0.781	21	41.95	287.5	25	41.01
1.172	20	59.32	431.25	16	64.04
1.563	16	74.58	575	13	80.30
1.953	8	84.75	718.75	6	91.01
2.344	6	90.68	862.5	3	96.07
2.734	3	94.49	1006.25	1	98.31
3.125	1	96.19	1150	1	99.44
3.516	2	97.46			
3.906	2	99.15			

Table 3B:

%	Nz (g)	Strain (με)	%	Nz (g)	Strain (με)
16.53	0.391	159.7	90.68	2.344	714.3
41.01	0.767	287.5	91.01	2.378	718.8
41.95	0.781	293.4	94.49	2.734	817.6
59.32	1.172	401.8	96.07	3.097	862.5
64.04	1.293	431.3	96.19	3.125	870.2
80.30	1.782	575	97.46	3.516	951.7
74.58	1.563	524.4	98.31	3.672	1006.3
84.75	1.953	634.7	99.15	3.906	1113.1

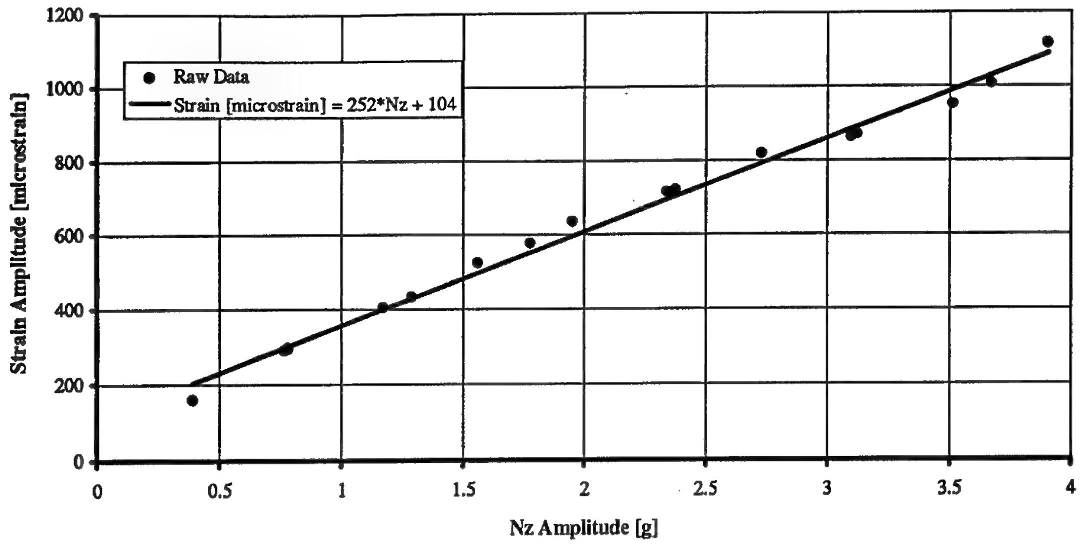


Figure 2: Load Versus Strain

This procedure has been implemented on a PC based computer program "Corrtest". The program was written in the "C" computer language. Features of the program include the following:

a. A parameter file is used to specify the strain/load ranges, expected correlation[3] values, channels for comparison, a defined error band[4] applied to the correlation value and whether transposition of a channel is required. The file is customised as necessary to suit the particular aircraft type. The program is applicable to any AFDAS aircraft.

b. The program computes the slope (either strain per *g* or strain per strain) relating to the four distributions (amplitudes, means, peaks and troughs) and provides this, plus the average of the four, as the output. The results are then compared to an expected range of correlation values (error band - a user input). The program also produces the regression coefficient of the fit between the two channels, and informs the user if this value is less than a predefined value, currently set at 0.90.

The program has been tested against the Ref 1 data and the results are shown in the Table 4. This shows that the program gives results consistent with the manual process. The program was then checked against a series of F/A-18 flights as described in Section 5.

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3 Based on calculated and/or separate testing and regression analysis, such as Table 5

4 The current "acceptable" error band was defined from the results presented in Section 5

Table 4: Comparison of Strain Per g Results

	Amplitudes	Means	Peaks	Troughs	Average
Ref 1 Results	347*	346	359	381	358
Modified Correlation Procedure (Manual)	252	350	314	313	307
Modified Correlation Procedure (Computer Program)	252	350	314	313	307

Note: These figures were obtained by using the positive section only of the load/strain data

* In Ref 1, end point data were modified to fit regression slope. In the modified process only data lying between the largest minimum cumulative occurrence mid point and the smallest maximum of the two data set is used (ie 16.53% and 9915% in Table 3B).

It should be noted that the program uses only data from one quadrant of the *g*/strain or strain/strain curve in conducting the regression. The reasons for this are:

a) bi-linearity of the gauges response (ie different slope between the positive and negative quadrants). An example of this behaviour is shown in Appendix 2, Figure A2.5.

b) The tendency of fighter aircraft to have many more positive *g* exceedences than negative. Hence the analysis is generally performed on the positive *g* data.

Therefore the program uses only data from the negative quadrant for transposed cases, or otherwise, only data from the positive quadrant.

Corrtest was designed to run in "batch" mode, that is, it searches for the end-of-flight (EOF) marker within each AFDAS output file (eg. M93354155.AFS) and produces outputs for each flight.

4. AFDAS Transfer Functions

Before a meaningful correlation procedure can be applied, it must be determined which of the AFDAS channels combinations will produce a linear transfer function (correlation), and the value of this function must be determined.

Transfer functions between several combination of AFDAS gauges at the various locations were developed using flight data obtained from the International Follow On Structural Test Project (IFOSTP) RAAF Aircraft Research and Development Unit (ARDU) flight trials conducted on F/A-18 A21-032, Ref 7 to 9. The flights, manoeuvres and configuration of the aircraft used in developing these transfer functions are detailed in Ref 10. The manoeuvres, PITS and configurations flown during these trials are considered representative of current RAAF F/A-18 flying.

Table 5: AFDAS Transfer Functions (for A21-032)

Pair No	Combination X versus Y		Description	Transfer Function µε Y = aX + C		R^2	σ (µε)
	X	Y		a*	C		
1	Ch3	Ch4	RHWF VS RHWR	1.38	73	0.755**	203
2	Ch11	Ch4	N_7 vs RHWR	230	-174	0.968	78
3	Ch2	Ch1	Y488 vs Y470.5 b'lhd	1.33	76	0.996	34
4	Ch1	Ch0	Y470.5 vs Y453 b'lhd	1.04	-8	0.994	48
5	Ch2	Ch0	Y488 vs Y453 b'lhd	1.39	70	0.983	73
6	Ch11	Ch0	N_7 vs Y453	-283	72	0.966	103
7	Ch11	Ch1	N_7 vs Y470.5	-271	74	0.969	96
8	Ch11	Ch2	N_7 vs Y488	-202	-4	0.964	75
9	Ch6	Ch7	Y645 vs Y657	1.1	-61	0.976	41
10	Ch11	Ch5	N_7 vs FF	105	-	0.712**	232
11	Ch11	Ch3	N_7 vs RHWF	130	-66	0.776**	128
12	Ch9	Ch8	Y598 vs Y566	1.15	-43	0.971	74

* Used in subsequent comparisons
** Poor correlation (due to PITS dependency) should be noted when considering subsequent results.

From this analysis it was found that twelve (12) combinations of AFDAS channels produced linear correlation functions. The results are summarised in Table 5, and further details are presented in Appendix 2. The transfer functions were derived to represent average values (ie not for specific PITS), and represent the flight configurations and regimes described in Ref 10.

As the relationships between some channels exhibit a bi-linear trend (eg. between positive and negative *g*), see Appendix 2 Figure A2.5, the transfer functions in Table 5 represent the quadrant containing the bulk of the data (ie. positive *g*).

Based on the derived transfer functions, a parameter file for use in the Corrtest program for the F/A-18 is presented in Table 6.

Table 6: F/A-18 Parameter File

Pair	CORRELATION X vs Y		Expected Value	Specified**	Transpose ?
No	Channel No. X	Channel No. Y	(slope)*	Error Band (±)	
1	3	4	1.38	0.2	N
2	11	4	230	50	N
3	2	1	1.33	0.3	N
4	1	0	1.04	0.2	N
5	2	0	1.39	0.3	N
6	11	0	-283	50	Y
7	11	1	-271	50	Y
8	11	2	-202	50	Y
9	6	7	1.1	0.2	N
10	11	5	105	50	N
11	11	3	130	26	N
12	9	8	1.15	0.2	N

* See Table 5

** "acceptable" range for resulting correlation slope.

5. F/A-18 AFDAS Correlation

For the purposes of testing the Corrtest program a number of F/A-18 AFDAS .AFS (data files) for a sample of aircraft were used. This data covered a period from July 1992 to Feb 1994. A typical output from the program for aircraft A21-017 is presented in Table 7. (Note, Table 6 parameters were used in the following analyses).

Table 7: Typical Corrtest Output

Date (DD/MM/YY) => 20/12/93
Time (HH:MM) => 09:29
Aircraft Number => < A21 017 >

FLIGHT 1

Channel X Y	AMPLITUDE		MEAN		PEAK		TROUGH
		MIN		MAX		AVERAGE	
~ ~	~~~	~~~~	~~~	~~~	~~~~	~~~~	~~~~
3 4	$1.63*F^{\phi}/0.95^{\varphi}$		2.10 *F/0.95		1.99 *F/0.99		2.17 *F/0.93
		1.18		1.58		1.97	
11 4	297.42*F/0.99		1063.78*F/0.96		442.65*F/0.95		926.81*F/0.94
		180.00		280.00		682.66	
2 1	1.05 /1.00		1.01*F /1.00		0.96 *F/1.00		0.97 *F/1.00
		1.03		1.63		1.00	
1 0	1.16 /1.00		1.02 /0.99		0.94 /0.97		1.19 /0.99
		0.84		1.24		1.08	
2 0	1.22 /1.00		1.02 *F/0.99		0.89 *F/0.98		1.20 /1.00
		1.09		1.69		1.08	
11 12	-350.34*F/0.98		-872.82*F/0.97		-603.67*F/1.00		-790.46*F/0.94
		-333.00		-233.00		-654.32	
11 13	-288.30/0.98		-715.06*F/0.96		-518.93*F/0.99		$-459.85*F/0.89*F^{\beta}$
		-321.00		-221.00		-507.43	
11 14	-279.73*F/0.97		-821.39*F/0.97		-365.80*F/0.94		-662.14*F/0.95
		-252.00		-152.00		-532.27	
6 7	0.84 *F/0.99		0.75 *F/0.95		0.92 /0.96		1.33 *F/1.00
		0.90		1.30		0.96	
11 5	74.15/0.99		162.53*F/0.99		101.39/0.98		196.17*F/0.98
		55.00		155.00		133.56	
11 3	151.38/0.97		481.37*F/0.99		197.38*F/0.95		457.43*F/0.98
		104.00		156.00		321.89	
9 8	0.63*F/0.97		0.68*F/0.98		0.79*F/0.96		0.78*F/0.99
		0.95		1.35		0.72	

where: min, max = predefined allowable range of slope.
average = average of amplitude, mean, peak and valley results
φ = regression coefficient of linear fit R^2
ϕ = "F" proceeding "*" implies slope outside predefined range (Table 6).
β = "F" proceeding "/" implies regression values outside predefined limit (ie 0.9). Note these values are excluded from the calculation of the average value.

A summary of the "amplitude" test output for the sample aircraft is presented in Table 8, whilst those for the mean, peak and trough are presented in Appendix 3.

Table 8: Amplitude Test for Sample Aircraft

AFDAS CHANNELS

0	Y453	[BLKHD]	6	Y645	[HSTAB]
1	Y470	[BLKHD]	7	Y657	[HSTAB]
2	Y488	[BLKHD]	8	Y566	[VTAIL]
3	RHWF	[WFOLD]	9	Y598	[VTAIL]
4	RHWR	[WROOT]	10	RH	[WTEF]
5	Y213	[FF]	11	Nz	[@CG]

	Aircraft:	A21-17	A21-17	A21-26	A21-38	A21-38	A21-44	A21-44	A21-107	A21-117
	File:	M93354155	M93302141	M93342099	M93334236	M93305211	M93335158	M93302132	M93343091	M93342091
	TOF*:	300	300	600	300	300	300	300	500/900	600
	FLT hrs:	5.4	27.7	20.9	27	10	18.4	12	16.1	33.1
CH: XY	ACTUAL#	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE
3 - 4	1.38	1.63	1.63	1.18	1.86	1.71	1.5	1.78	2.33	2.05
11 - 4	230	297	318	201	290	314	320	328	212	231
2 - 1	1.33	1.05	0.95	1.23	1.12	1.31	1.03	0.99	0.91	1.05
1 - 0	1.04	1.16	1.39	0.73	1.42	1.3	1.35	1.32	0.97	1.23
2 - 0	1.39	1.22	1.3	0.92	1.59	1.71	1.43	1.33	0.92	1.44
11 - 0	-283	-350	-399	-154	-375	-392	-418	-398	-223	-274
11 - 1	-271	-288	-285	-196	-276	-304	-301	-293	-224	-204
11 - 2	-202	-279	-305	-170	-239	-229	-301	-293	-248	-194
6 - 7	1.1	0.84	1.23	1.3	1.13	1.04	1.16	1.1	1.42	1.61
11 - 5	105	74	87	89	96	87	66	62	45	37
11 - 3	130	151	149	123	121	120	149	140	83	91
9 - 8	1.15	0.78	0.68	0.7	0.78	0.65	0.61	0.72	0.59	0.54

* TOF = type-of-flight code, see Ref 4.
# Transfer functions from Table 5, which were derived for A21-032

Even though some channel pair results differ significantly from the "actual" transfer function, and considering that no allowances have been made between different aircraft configurations or PITS, the results nevertheless show consistency, even for those channel pairs noted as having poor linear relationships in Table 5.

The statistics from this analysis are presented in Table 9. The data used consisted of the 9 AFDAS files [6 aircraft], totalling approximately 170 flying hours.

From the results in Table 9 it can be seen that consistent correlations were achieved for all four data sets obtained from the RMP data. The values of standard deviations were reasonable, and were used in defining the expected range of the correlations, against which each method is tested. From these results it was concluded that the AFDAS data used in this investigation was free of irregularities, and consistent with typical usage of the aircraft during the periods considered.

Table 9: Sample Aircraft Correlation Statistics

(a)		AMPLITUDE		MEAN		PEAK		TROUGH	
CH X : Y	ACTUAL	μ	σ	μ	σ	μ	σ	μ	σ
3 - 4	1.38	1.74	0.33	2.23	0.28	2.08	0.19	2.21	0.26
11 - 4	230	279	50	623	174	433	37	559	145
2 - 1	1.33	1.07	0.13	1.09	0.17	1.05	0.15	1.02	0.09
1 - 0	1.04	1.21	0.22	1.07	0.24	1.08	0.26	1.21	0.24
2 - 0	1.39	1.31	0.27	1.2	0.39	1.2	0.38	1.28	0.3
11 - 0	-283	-331	93	-557	164	-481	115	-524	160
11 - 1	-271	-263	43	-448	117	-419	59	-392	70
11 - 2	-202	-251	48	-487	165	-382	68	-387	167
6 - 7	1.1	1.2	0.22	1.3	0.33	1.23	0.3	1.33	0.23
11 - 5	105	71	21	176	73	147	45	186	59
11 - 3	130	125	25	273	86	204	24	267	94
9 - 8	1.15	0.67	0.08	0.79	0.29	0.75	0.07	0.65	0.11

b) Combined (average of all) Methods :

CH X : Y	ACTUAL	μ	σ
3 - 4	1.38	2.1	0.32
11 - 4	230	479	173
2 - 1	1.33	1.06	0.14
1 - 0	1.04	1.18	0.23
2 - 0	1.39	1.3	0.32
11 - 0	-283	-477	191
11 - 1	-271	-377	139
11 - 2	-202	-382	166
6 - 7	1.1	1.25	0.28
11 - 5	105	124	63
11 - 3	130	216	87
9 - 8	1.15	0.72	0.16

Where : μ - Mean Slope
σ - Standard Deviation Slope

Of the four RMP data sets, the amplitude test gave the most consistent values (smallest σ) and these where closest to the derived transfer function. Of the combinations of channels tested, Ch 2-1 and Ch 9-8 produced the smallest standard deviations, and this was attributed to the fact that the specified range of these channels were close to their optimal values (ie. compare Table 2 and Appendix 1). It should also be noted that although the results of the correlation containing the N_Z channel appear good, solution of the discrepancies discussed in Section 6 may affect the results. If these channels are ignored, then the standard deviation of the average value of all four methods is within 25% of the predicted transfer function. It is therefore considered feasible to use the expected correlation range (transfer function ± σ) for particular channel combination comparisons and thus check on the quality and consistency of the AFDAS data.

As the aircraft configuration and missions vary with time, it can be expected that the correlation values will also vary. Theoretically, the correlation (or transfer function) will vary during a particular flight. As an example of this, as the aircraft consumes fuel from the wing internal/external tanks, the wing inertia will change thus affecting the strain response to g at the wing root sensor etc. Thus the correlation results must be considered as "period" averages.

In order to ascertain this variability, approximately one years AFDAS .AFS files from aircraft A21-117 and A21-017 were obtained and were "run" through Corrtest.

Most of the following AFDAS.AFS files were used in this analysis. It should be noted that for **A21-117** Flights 3,4,7 and 9 were not included in the subsequent analysis due to insufficient data points (see Table 10). The EOF markers indicate that the data period in question spans approximately 20 months for aircraft A21-117 and 12 months for A21-17.

A21 - 117			A21 - 17		
Flt 1 :	M92213093.AFS	EOF[5] 22/07/92	Flt 1 :	M93090203.AFS	EOF 31/03/93
Flt 2 :	M93251100.AFS	EOF 15/09/92	Flt 2 :	M93105183.AFS	EOF 15/04/93
Flt 3 :	M92244158.AFS	EOF 24/08/92	Flt 3 :	M93120172.AFS	EOF 30/04/93
Flt 4 :	M93034126.AFS	EOF 03/02/93	Flt 4 :	M93167101.AFS	EOF 31/05/93
Flt 5 :	M93064107.AFS	EOF 22/02/93	Flt 5 :	M93211159.AFS	EOF 30/07/93
Flt 6 :	M93125130.AFS	EOF 05/05/93	Flt 6 :	M93302141.AFS	EOF 29/10/93
Flt 7 :	M93196160.AFS	EOF 15/07/93	Flt 7 :	M93334201.AFS	EOF 30/11/93
Flt 8 :	M93228102.AFS	EOF 13/08/93	Flt 8 :	M93354155.AFS	EOF 20/12/93
Flt 9 :	M93243162.AFS	EOF 17/08/93	Flt 9 :	M94059181.AFS	EOF 28/02/94
Flt 10 :	M93302161.AFS	EOF 29/10/93	-	-	-
Flt 11 :	M93342091.AFS	EOF 08/12/93	-	-	-
Flt 12 :	M94032080.AFS	EOF 31/01/94	-	-	-

The results for this analysis are presented in Figures 3 and 4. The statistical results from these analyses (averages of the flights for each aircraft) are presented in Tables 10 and 11.

[5] In the current F/A-18 AFDAS, the EOF marker is only triggered when the data is downloaded, not as was intended, on a flight by flight basis. Thus as one AFS file may represent many flights, it was not possible to determine the TOF codes for these periods. The RAAF are currently addressing this problem.

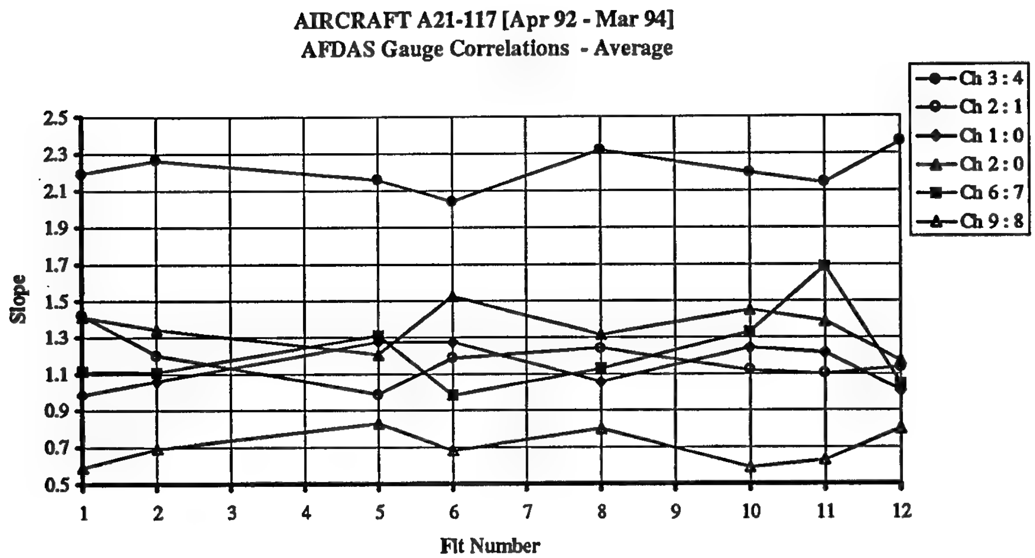

Figure 3: Aircraft A21-117 Gauge Correlations

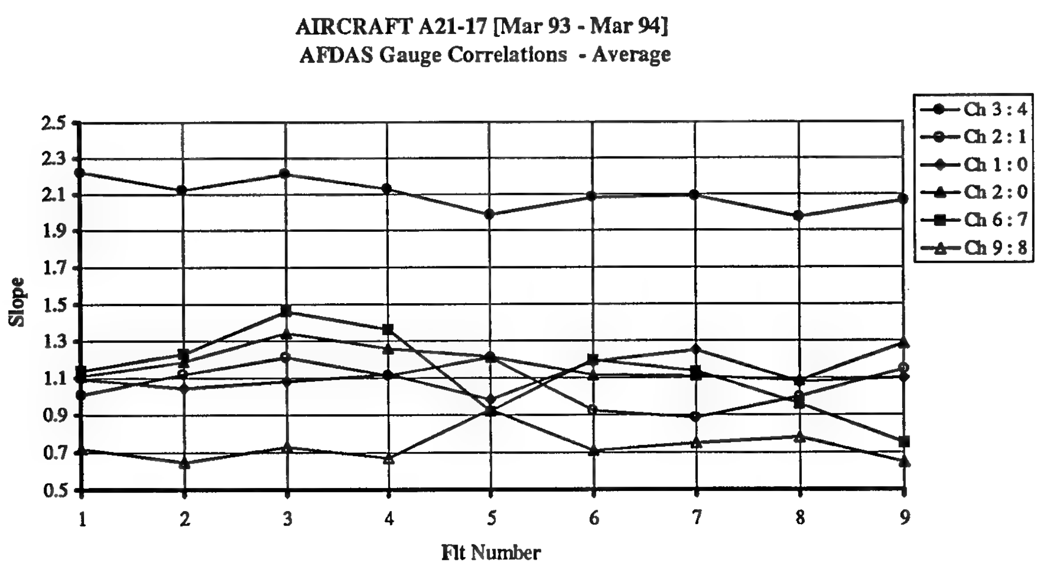

Figure 4: Aircraft A21-017 Gauge Correlations

Table 10: Correlation Statistics for A21-117

a) Number of cycles/flight[ϕ]

	TURNING POINTS*											
CH #	Flt[ϕ] 1	Flt 2	Flt 3	Flt 4	Flt 5	Flt 6	Flt 7	Flt 8	Flt 9	Flt 10	Flt 11	Flt 12
0	1374	684	212	96	1356	1540	24	1688	214	4150	14430	502
1	2366	1184	502	252	2614	2432	50	2884	382	8314	26104	918
2	1222	694	232	102	1280	1454	22	1634	214	3552	9720	514
3**	6236	3100	1614	944	4524	3740	86	7746	1270	20372	72438	3408
4	2622	1334	576	268	2542	2548	48	3406	422	9660	25936	1028
5	360	216	74	66	338	260	10	396	42	960	1780	202
6	1938	1086	378	258	1044	1188	22	2282	184	5260	3350	898
7	2202	1472	550	544	1952	890	14	3496	276	10396	3260	1284
8	1792	768	412	308	760	456	18	1872	182	5026	3510	602
9**	9618	5092	4554	3676	9906	2072	60	10924	2074	33030	21596	6276
10	426	260	54	56	286	400	8	572	34	860	1010	200
11	906	522	112	116	908	1036	18	1198	76	2190	3600	450

Note : Flights 3,4,7 and 9 have not been included in the subsequent analysis due to insufficient data points.

* Range Pair Counts = Turning points / 2

** Relatively large counts due to wing or empennage buffet, see Ref 4.

ϕ Most "flight, FLT" contain more than one flight.

b) Statistics (average of all flights)

		AMPLITUDE		MEAN		PEAK		TROUGH	
CH X : Y	ACTUAL	μ	σ	μ	σ	μ	σ	μ	σ
3 - 4	1.38	2.14	0.24	2.28	0.27	2.21	0.09	2.22	0.25
11 - 4	230	248	26	657	111	424	59	533	126
2 - 1	1.33	1.08	0.08	1.28	0.20	1.26	0.23	1.09	0.06
1 - 0	1.04	1.31	0.08	1.01	0.21	0.96	0.22	1.28	0.11
2 - 0	1.39	1.44	0.05	1.3	0.2	1.26	0.18	1.41	0.07
11 - 0	-283	-299	24	-570	77	-460	64	-529	108
11 - 1	-271	-220	17	-472	29	-374	56	-385	96
11 - 2	-202	-208	20	-438	76	-323	42	-365	93
6 - 7	1.1	1.19	0.23	1.03	0.43	1.29	0.22	1.34	0.29
11 - 5	105	53.6	7.8	-	-	44	18.5	-	-
11 - 3	130	93	14	273	87	193	25	254	86
9 - 8	1.15	0.62	0.15	0.88	0.16	0.74	0.21	0.56	0.09

c)   Combined (or averaged of all) 4 RMP data sets :

CH X:Y	ACTUAL	μ	σ
3 - 4	1.38	2.21	0.22
11 - 4	230	465	175
2 - 1	1.33	1.18	0.18
1 - 0	1.04	1.14	0.22
2 - 0	1.39	1.35	0.15
11 - 0	-283	465	127
11 - 1	-271	363	107
11 - 2	-202	333	104
6 - 7	1.1	1.21	0.31
11 - 5	105	50.3	12.5
11 - 3	130	203	93
9 - 8	1.15	0.70	0.19

Table 11: Correlation Statistics for A21-017

a)   Number of cycles/flight

CH #	TURNING POINTS*								
	Flt 1	Flt 2	Flt 3	Flt 4	Flt 5	Flt 6	Flt 7	Flt 8	Flt 9
0	1596	2722	3510	6938	800	2734	7772	846	6812
1	3010	6240	9198	17058	1912	6368	18932	1788	18332
2	1618	3000	3644	6630	918	3030	8398	956	7528
3	4922	10250	16186	20090	4262	15304	39416	2854	48538
4	2472	4754	5968	11058	1536	5284	14362	1356	13276
5	214	408	412	398	120	392	642	114	866
6	1014	1262	780	1584	720	2228	3480	680	2522
7	1606	2086	1442	2646	1454	4084	5068	906	4384
8	462	676	776	1202	624	2316	2646	366	2744
9	3064	3722	4418	7474	3458	9980	11586	1656	13338
10	444	628	500	612	148	806	1158	264	1010
11	998	1528	1302	2246	568	1550	3524	526	3288

* Range Pair Counts = Turning points / 2

b)   Statistics (average of all flights)

		AMPLITUDE		MEAN		PEAK		TROUGH	
CH X:Y	ACTUAL	μ	σ	μ	σ	μ	σ	μ	σ
3 - 4	1.38	1.87	0.19	2.19	0.12	2.13	0.09	2.15	0.17
11 - 4	230	399	149	796	188	475	75	717	178
2 - 1	1.33	1.06	0.08	1.11	0.17	1.07	0.17	1.03	0.07
1 - 0	1.04	1.21	0.14	1.01	0.1	1.00	0.08	1.2	0.06
2 - 0	1.39	1.28	0.05	1.12	0.13	1.11	0.16	1.24	0.07
11 - 0	-283	-506	175	-710	125	-578	49	-702	94
11 - 1	-271	-421	162	-633	140	-500	36	-536	128
11 - 2	-202	-392	136	-633	104	-441	63	-575	84
6 - 7	1.1	1.19	0.24	1.08	0.29	1.14	0.32	1.1	0.22
11 - 5	105	84	24	111	32	109	13	144	48
11 - 3	130	182	66	336	74	221	29	305	67
9 - 8	1.15	0.68	0.09	0.72	0.25	0.85	0.17	0.69	0.16

Where : μ - Mean Slope
σ - Standard Deviation of the Slope

c) *Combined (or averaged of all) 4 RMP data sets :*

CH X:Y	ACTUAL	μ	σ	% σ
3 - 4	1.38	2.09	0.19	9
11 - 4	230	597	222	37
2 - 1	1.33	1.07	0.13	12
1 - 0	1.04	1.1	0.14	13
2 - 0	1.39	1.19	0.13	9
11 - 0	-283	-624	144	23
11 - 1	-271	-522	143	27
11 - 2	-202	-510	138	27
6 - 7	1.1	1.13	0.26	23
11 - 5	105	111	37	33
11 - 3	130	261	86	33
9 - 8	1.15	0.73	0.18	25

From these results it can be seen that consistent correlations (low σ) were achieved for each of the 4 data sets extracted from the AFDAS RMP data, except the result for A21-117 FLT 11 which indicates a problem with that data. The values of standard deviations were reasonable, and ignoring again the N_Z channel, were within 25% of the predicted transfer function.

It can be seen that the results for each aircraft were consistent (similar σ) over the periods considered. Again, it is considered feasible to use the expected correlation range for particular channel comparisons and thus check on the quality and consistency of the AFDAS data. The form in which Figures 3 and 4 are presented is considered the most useful, as trends over a period of time can be readily deduced, and thus an irregular flight (or data) easily seen.

From these results it was concluded that the AFDAS data (except for the Nz problem and FLT 11, A21-117) used in this investigation were free of irregularities, and consistent with typical usage of the aircraft during the periods considered. Note as the TOF codes are unknown, no assessment of the effect of configuration and PITS could be conducted.

It is of interest to note the different total cycle counts in Tables 10a and 11a, for AFDAS channels 6 and 7, which are both located at the RH Y657 HT support spindle. In most cases it can be seen that the number of counts for channel 7 is of the order of twice that for channel 6. This can be attributed to the fact that the AFDAS algorithm effectively discriminates PVs. No maxima or minima exists where the input variable oscillates about any one level boundary without crossing another, and are thus ignored. As the ranges for channels 6 and 7 are different, this leads to different discrimination levels, which in turn lead to a different total cycle counts. As the omitted cycles are small, the variation in discrimination between the two channels does not significantly affect the use of the AFDAS data.

When comparing results from different aircraft, apart from the mission and configuration differences already mentioned, variations between individual gauge response should also be considered, see Ref 11. Due to varying gauge factors, structural component build differences and sensor positioning errors, gauges at nominally similar position on different aircraft may produce different results for nominally exact manoeuvres. All these factors need to be considered if comparing inter-aircraft correlations[6] (ie one data set each from two different aircraft).

A similar analysis has been conducted for AFDAS data from the F-111C aircraft, and these results are presented in Ref 6.

From observations from the analyses conducted above, the recommended slope and error band to be used when conducting data screening, based on the average result of the 4 correlations, is presented in Table 12.

Table 12: Recommended F/A-18 Parameter File

CORRELATION X vs Y		Derived	Recommended	Initial	Recommended
Channel No. X	Channel No. Y	slope (Table 5)	slope (avg)	Error Band (±) (Table 5)	Error Band (±)
3	4	1.38	2.1	0.2	0.2
11	4	230	-	50	-
2	1	1.33	1.1	0.3	0.3
1	0	1.04	1.1	0.2	0.3
2	0	1.39	1.3	0.3	0.3
11	0	-283	-	-	-
11	1	-271	-	-	-
11	2	-202	-	-	-
6	7	1.1	1.1	0.2	0.4
11	5	105	-	50	-
11	3	130	-	26	-
9	8	1.15	0.7	0.2	0.2

- to be reassessed after N_z problem rectified

6. AFDAS N_Z Channel

During the development of the Corrtest program, several discrepancies were noted in the F/A-18 AFDAS N_Z channel from in-service data. Table 13 presents flight data for aircraft A21-034, for 4 flights conducted over the period 22 - 25 October 1991 (total flight time approx. 4 hr).

[6] Future work may consider this as a possible gauge calibration technique.

The major observations that have been made from this table are:

a) There are no peaks at level 14 and no valleys at level 5 (level 5 has 1 count but this is suspect) but the adjoining rows (peaks 13 and 15) and adjoining columns (valleys 4 and 6) contain relatively large number of counts. It is also worth noting that peak level 14 is one level away from the highest level at which counts are found, and valley level 5 is one level away from the lowest level at which valleys are found.

Table 13: AFDAS N_z RMP Table for A21-034

PEAKS

Peak \ Valley	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0																
1																
2																
3																
4																
5																
6																
7							5									
8					1		8	1928								
9						1	12	984	674							
10							8	426	211	281						
11					118		9	176	59	44	107					
12					17		3	102	9	11	19	75				
13					28		3	42		1	1	3	34			
14																
15					3			2	1							

VALLEYS

Note: Current range set as

± 10*g* *ie* $\Delta Nz = 20/16 = 1.25$

b) From available information the range is set at ±10*g* (±5 volts). Counts are found in levels 4 and 15 which this would indicate very high and very low values of N_z (approx -4.5*g* and > 8.75*g*) that are not likely to be experienced by the aircraft.

All F/A-18 AFDAS N_z data investigated thus far has indicated the existence of this phenomenon. At this stage it was assumed that an explanation may rely on discovering the actual sensor range and also whether an in-built deadband has been incorporated into the online processing of the N_z data (see Section 6.1).

Data was also extracted from the aircraft's on-board data acquisition system known as the F/A-18 "Maintenance Signal Data Recording System (MSDRS)". The MSDRS is an omnibus system which records time based data from the aircraft's data bus and

strain sensors located at fatigue critical locations throughout the aircraft, see Ref 4. It was found that the maximum and minimum values of N_Z for these same flights were 6.84*g* and -0.04*g* respectively.

Since the data corresponded to the same period, it can be inferred that the maximum value that was recorded by the AFDAS should have been 6.84*g* and the minimum value -0.04*g*, therefore the AFDAS range was scaled down from ±10*g* to [-2.5*g*, 7.5*g*] to achieve the same maximum and minimum values, and these were used in the preceding correlation analysis.

It should be noted, that unlike other aircraft's installations, the F/A-18's SRPC does not contain an in-built accelerometer, but uses the output from the aircraft's primary accelerometer unit, Ref 12.

6.1 Accelerometer Calibration

One possible explanation of the discrepancies in the F/A-18 AFDAS N_z channel may be due to inaccurate information concerning the accelerometer output which is fed into AFDAS. To resolve this a calibration of the appropriate accelerometer was performed. The RAAF provided AMRL with an F/A-18 linear electrical accelerometer (P/N 153C6845G9, Serial No: SBH004) and associated wiring diagrams for this purpose.

Two separate investigations were conducted at AMRL to calibrate the accelerometer (note the unit comprises of 4 individual sensors, two primary - normal and lateral, and two backup), namely:

a. static calibration conducted on a rotatable vertical "dividing head" (360°),
b. dynamic calibration on a rotating table.

In (a) the output voltage of the sensor is measured as the unit is rotated in increments through 360°. Higher values of *g* are simply scaled linearly from ±1*g*.

In conducting (b) the unit is mounted to the base of a circular platen, which is capable of rotating at constant rates (ω). Power to the unit, and output from the unit, is provided via electrical slip rings. The distance from the centre of the platen to the effective cg of the sensor (r) is measured, and the radial acceleration is then calculated ($\ddot{a} = \omega^2 r$).

Here some uncertainties may be introduced, namely:

a. calibration errors in the rate table rotational rates,
b. uncertainties as to the effective location of the sensor cg,
c. inaccuracies in measuring the radius at which the sensor was mounted.

Of the two techniques, (a) is the classical method of calibrating a sensor to ±1*g*, and is considered the most accurate.

In conducting (a) the orientation of the unit determined which sensor would respond to the gravitational acceleration. In conducting (b) the orientation of the unit determined which sensor would respond to the radial acceleration.

The results of the trials are shown in Figures 5 and 6, and summarised below:

a.	Normal	±1g = ±0.5 volt	Fig 5
b.	Normal	±1g = ±(1.94 volt + 1.16)	Fig 6

Note: for case (a), Figure 5, the zero offset was removed prior to calibration, and a sine wave fitted to the resulting data.

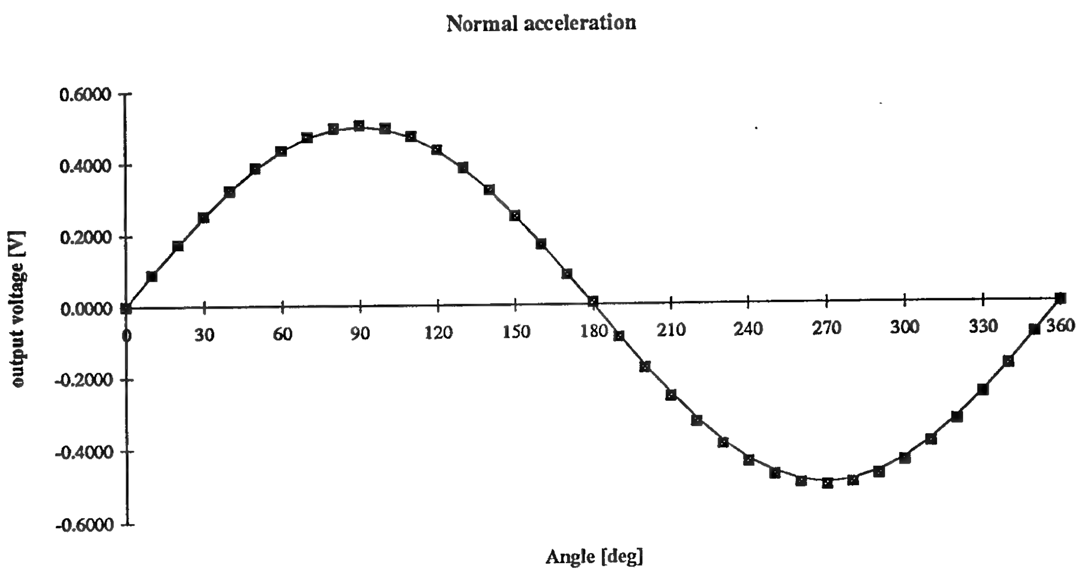

Figure 5: Calibration of Normal Accelerometer on Dividing Head (Method A)

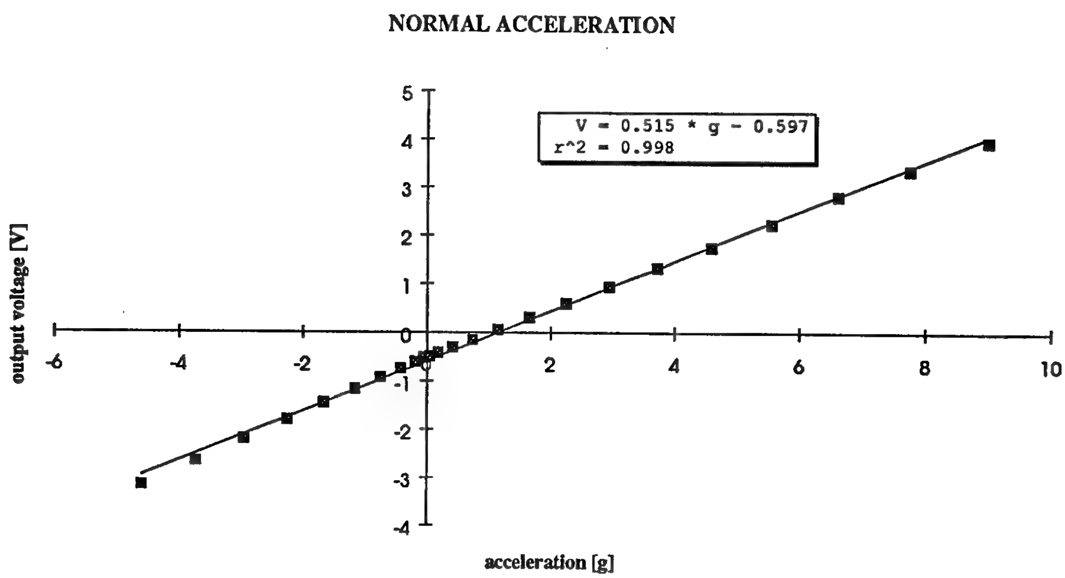

Figure 6: Calibration of Normal Accelerometer on Rate Table (Method B)

From these results it is concluded that the accelerometer response is "as specified" only if the zero offset is removed (ie for normal accelerometer : ±10g = ±5 volt), as was done for case (a). In the AFDAS the relationship g = 2*Volts is used, therefore the 1 volt offset (as shown by (b)) is not accounted for.

No deadband was detected during these calibrations.

Although the detected zero offset will affect the AFDAS N_z channel range, it is unclear whether this will also affect the observed "missing" data in certain levels. Therefore the anomalies detected in the AFDAS may be due to other factors.

7. Discussions and Recommendations

The method described in this report, along with the program developed, shows good potential as a means of screening AFDAS usage data. It is recommended that operational AFDAS data be periodically "screened" using this method, and the average result for each aircraft and period be monitored over time. If an irregularity is noted, that individual data set leading to the observation, should be interrogated. If the cause (eg spurious large count in a cell) can be determined then the data file can be "salvaged", otherwise the file should be omitted from subsequent aircraft usage analyses. It should be noted that the data should first be screened through the Hawker de Havilland program to determine the existence of gross errors.

The expected range of the correlation between channels, will need to be re-assessed once the AFDAS SRPC's are modified to incorporate the optimum channel ranges.

Due to the unavailability of flight data to develop a theoretical transfer function between the sensors on the vertical tails, alternative data was used. Further flight data are required to validate the function developed for these sensors.

Once EOF markers can be triggered on a flight-by-flight basis, the TOF code can be found via the MSDRS for each flight. This will enable aircraft configuration and average PITS to be determined. If this is achieved, then sensor to sensor transfer functions can be derived to be PITS and/or configuration specific. This will improve the regression values for some of the sensors presented in Table 5. The prescribed error band for specific sensor to sensor correlation can then be reduced. The expected range of the correlation between channels, on a flight-by-flight basis should be evaluated once the automatic EOF marker is incorporated into the F/A-18 AFDAS.

The calibration of the F/A-18 accelerometer unit indicated that its output was not as specified by the manufacturer. It is recommended that the F/A-18 AFDAS be modified to account for the detected 1 volt offset on the N_z channel. As other anomalies were also detected in the AFDAS N_z channel it is recommended that further investigations be conducted, once the AFDAS has been modified.

8. Conclusions

This report presents the details of the automation, refinement and application of a technique originally developed by Howard of AMRL to correlate two individual AFDAS data channels, as a method of data screening or validation. A PC based program developed to implement the technique routinely for operational AFDAS flight data is also described. Although the technique is here in demonstrated by using operational F/A-18 AFDAS data, the approach is not aircraft type dependent, and is intended for general AFDAS (or any range mean pair) data screening purposes.

This method can now be used to routinely assure AFDAS data integrity, from which fatigue damage assessment can be subsequently conducted, even possibly at the individual aircraft squadron level. The data screening capability will enhance the potential of AFDAS as a powerful fatigue life management tool.

9. Acknowledgment

The authors wishes to acknowledge the assistance and support from Ms A. Houston who developed the PC based software, CORRTEST. Also to Messrs B. Aktepe, D. Graham and D. Smith of Airframes and Engines Division AMRL, for assistance and input. This work was sponsored under TASK AIR92/461.

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12. Communication from FLTLT D. Trentin ASI to L. Molent 9 Feb 1995.

Appendix 1

Recommended Afdas Max/Min Data Ranges (Including ARDU Phase I and II Data)

No	Data** Source	Max	Min	g^{θ} LOAD	Measurand Description
0	ARDU	820		-2.5	AFDAS L/H Frame @FS453
	ST-16$^{\phi}$		-2500	7.5	
1	ARDU	730		-2.5	AFDAS L/H Frame @FS470.5
	ARDU		-2600	7.5	
2	ARDU	600		-2.5	AFDAS L/H FRAME @FS488
	MCAIR		-1800	7.5	
3	ARDU	1300		7.4	AFDAS R/H Wing Fold @BL162.5
	ARDU		-980	-2.5	
	ARDU***	1300			
	ARDU***		-1200		
4	estimate@	2100			AFDAS R/H Wing Root @FS470.5
	ARDU		-650	-2.5	
5	MCAIR	1600			AFDAS Canopy Sill @FS213
	MCAIR		-550		
6	ARDU	1500		7.5	AFDAS Horz. Stab. @FS645
	estimate		-1000		
	ARDU***	1500			
	ARDU***		-1000		
7	ST-16	2000			AFDAS Horz. Stab @FS657
	ST-16		-2500		
	ARDU***	1500			
	ARDU***		-1200		
8$^{\otimes}$	ST-16	1700			AFDAS Vert. Tail Stub @FS566
	ST-16		-1900		
9	MCAIR	1700			AFDAS Vert. Tail Stub @FS598
	MCAIR		-1700		
10	estimate	1650			AFDAS R/H TE Flap @BL59
	estimate		-2300		
	ARDU***	1650			
	ARDU***		-1650		

* No other data available - (based on A21-034 AFDAS data)

** Data rounded off

*** Based on ARDU Phase II data; original (Ref 4) value retained if close

@ Estimate between McAIR prediction at 9.25*g* and measured at approx. 7.5*g* (ARDU)

θ Where applicable $\otimes$ No valid flight trails data available

Modification to Ref 4 recommended value

ϕ McAIR F/A-18 fatigue test, referred to as ST-16

Note: Values related to typical max and min loads experienced by RAAF F/A-18, namely 7.5g and -2.5g

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Appendix 2

Development of Transfer Functions for F/A-18 AFDAS Sensors

The basis of this report, relies upon obtaining linear relations between AFDAS sensor locations so that correlation analysis can be performed and data integrity checked. For this reason the AFDAS sensors detailed in this report, and shown below in Figure A2.1 were investigated to determine linear transfer functions between them, relating either strain vs strain or strain vs Nz (vertical load factor), for the various locations. Data used for the analysis was that acquired during the Aircraft Research & Development Unit (ARDU) IFOSTP Task 21-01 phase I and II flight trails, (Ref 7 to 9).

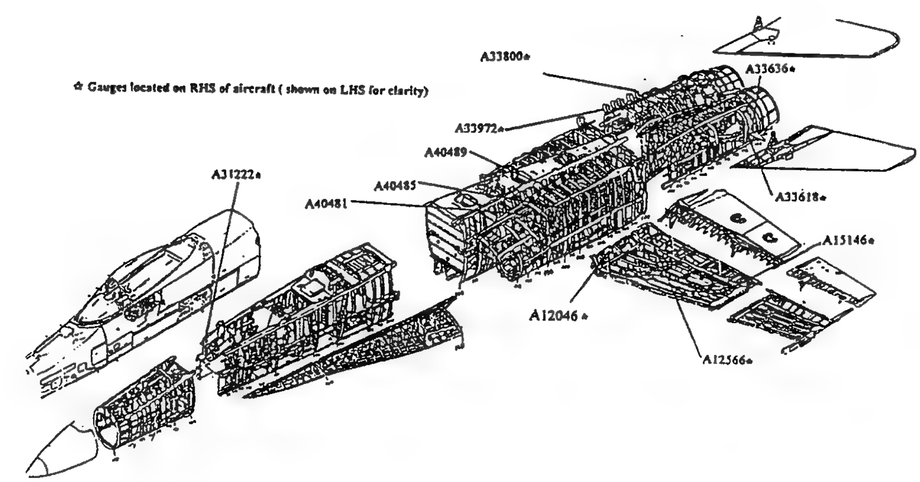

Figure A2.1 : Location of F/A-18 AFDAS Sensors

During operational usage of the aircraft, AFDAS data is collected whilst the aircraft flies under various mission types and stores configurations. There are no means of determining these parameters solely from the AFDAS. Once the EOF markers are configured to automatically trigger at the end of each flight, then the TOF and PITS can be found for the equivalent MSDRS data files. As this is not yet possible "average" result transfer functions (all PITS) were determined.

CHANNEL : SENSOR : LOCATION

CH 0 : [A40481] : LH BLKHD @ Y453
CH 1 : [A40485] : LH BLKHD @ Y470.5
CH 2 : [A40489] : LH BLKHD @ Y488
CH 3 : [A15146] : RH WFOLD @ OML
CH 4 : [A12046] : RH WROOT @ Y470.5
CH 5 : [A31222] : RH FF @ Y213
CH 6 : [A33618] : RH HT @ Y645
CH 7 : [A33636] : RH HT @ Y657
CH 8 : [A33972] : RH VT @ Y566
CH 9 : [A33800] : RH VT @ Y598
CH 10:[A12566] : RH WTEF
CH 11:[Nz] : @ CG

TRANSFER FUNCTION RESULTS :

Except were stated otherwise, the transfer functions were derived using ARDU Phase I data, incorporating all available manoeuvre and mission types, (ie various store configurations), see Ref 4. The data was then reduced to a more manageable size (approximately 10,000 data points) by selecting every 9th point from the total data base.

1) CH 3 : 4 [WF - WR]

Problems affecting the success of this transfer function are related to strain response differences at various PITS. The results, (Figure A2.2) do show a trend but as the statistics indicate, the relationship is poor. Data used in the analysis was that acquired during the Phase II flight trials, and involves a filtered selection of all available data, (ie all manoeuvre types and store configurations). Note that the ARDU Phase I WF gauge was not operational, see Ref [4].

A12046 [$\mu\varepsilon$] = 1.38*A15146 [$\mu\varepsilon$] + 73
R^2 = 0.775
Standard Error = 203 $\mu\varepsilon$

2) CH 11 : 4 [Nz - WR]

The results presented in Figure A2.3 show a general linear relation between wing root strain and vertical load factor (ie positive Nz), but a "washing off" of WR strain at high *g* occurs. The investigation into the scatter that existed showed a dependence on high angle of attack, high Nz combinations, as well as high roll rate conditions. The high scatter associated with roll rate occurs because the wing root strain induced under high rolling conditions tends to be independent of Nz. The situation associated with high alpha conditions, occurs due to a combination of forebody lift, (ie lift generated by the Leading Edge Extension) and the F/A-18's active control system alleviating load on the outer wing. This is further demonstrated in Figure A2.4 which shows data generated from all available ARDU phase I ground attack mission profiles, showing a lack of load wash off due to the fact that the maximum angle of attack reached is fairly low. As a final note, some differences were detected resulting from varying wing store configurations, however these were considered minor.

The important aspect of all this, is that generally the resulting transfer function relating WR strain to Nz is consistent when applied to various conditions, as described above. Therefore the correlation test software is able to return a stable average transfer function result. (The following refers to all conditions).

A12046 [με] = 230 * Nz - 174
R^2 = 0.968
Standard Error = 78 με

Note that this transfer function exhibited a bi-linear relationship, with the negative strain region, (negative Nz), having a different slope to the positive region, see Figure A2.5, (generated from all available ACM data). Note that the above regression equation considers only the positive quadrant.

3) CH 2 : 1 [Y488 - Y470]

This produced good results with low scatter, see Figure A2.6.

A40481 [με] = 1.33 * A40489 [με] + 76
R^2 = 0.996
Standard Error = 34 με

4) CH 1 : 0 [Y470 - Y453]

This produced good results with low scatter, see Figure A2.7. Note also that no bi-linearity exists between the positive and negative strain regions.

A40481 [με] = 1.04 * A40485 [με] - 8
R^2 = 0.993
Standard Error = 48 με

5) CH 2 : 0 [Y488 - Y453]

This produced good results with low scatter, see Figure A2.8.

A40481 [με] = 1.39 * A40489 [με] + 70
R^2 = 0.983
Standard Error = 73 με

6) CH 11 : 0 [Nz - Y453]

Same comments as (2) apply, however the effects are not as pronounced, see Figure A2.9. Note also that this location along with the other bulkhead locations experience compressive (-ve) strain with positive load factors.

A40481 [με] = -283 * Nz + 72
R^2 = 0.966
Standard Error = 103 με

7) CH 11 : 1 [Nz - Y470]

Same comments as (6) apply, see Figure A2.10.

A40485 [με] = -271 * Nz + 74
R^2 = 0.969
Standard Error = 96 με

8) CH 11 : 2 [Nz - Y488]

Same comments as (6) apply, see Figure A2.11.

A40489 [με] = -202 * Nz - 4
R^2 = 0.964
Standard Error = 75 με

9) CH 6 : 7 [HT645 - HT657]

As shown in Figure A2.12 this transfer function shows a high degree of linearity, yielding good correlation statistics. However upon further examination under high roll rate conditions the response appears to produce two sets of data, each with a linear relationship but with slightly different slopes. Note however for the purpose of this report it is considered that the single linear prediction was acceptable.

A33636 [με] = 1.1*A33618 [με] - 61
R^2 = 0.976
Standard Error = 41 με

10) CH 11 : 5 [Nz - FF]

As shown in Figure A2.13 this transfer function does not produce very good results, the scatter that exists is possibly due to combinations of dynamic pressure, altitude and mach number (ie *Points In The Sky* - PITS). Note however that generally the data follows a trend and an average slope is available.

A31222 [με] = 105*Nz + 50
R^2 = 0.712
Standard Error = 232 με

11) CH 11 : 3 [Nz - WF]

The transfer function statistics produced for this location do not indicate a high degree of linearity, due to PITS variations. However Figure A2.14 does indicate that a fairly well defined band does exist in which a slope can be determined. Again for the purposes of the correlation test software this result is considered sufficient. Note that further analysis is required to establish which factors are producing the banding or scatter within the plot. This may be possible with the introduction of the automated EOF marker. Note also that this plot was generated using a selection of all available ARDU Phase II data, due to the WF gauge being inoperative during ARDU Phase I.

A15146 [με] = 130*Nz - 66
$R^2 = 0.776$
Standard Error = 128 με

12) CH 8 : 9 [VT566 - VT598]

Data obtained from the ARDU Phase I and II flight tests yielded spurious data for the strain sensor A33972, (vertical tail stub), see Ref 4,10. For this reason data available from McAIR's (McDonnell Aircraft Company) ST-16 fatigue test was used in developing the transfer function at this location, see Ref 4. The following PITS were used to simulate loading conditions in this fatigue test :

1/ Mach 0.8 @ Sea Level
2/ Mach 0.95 @ 15,000 ft
3/ Mach 1.1 @ Sea Level

An investigation of this data determined that differences in strain response occurred due to these varying PITS. Again however for the purpose of this report an average transfer function is considered to give an acceptable result, see Figure A2.15. Note that the clearly visible separate data series in this Figure, occurring at high negative strain values is due to the *Mach 1.1 @ Sea Level PITS.*

1/ A33972 [με] = 0.99*A33800 [με]
$R^2 = 0.964$
Standard Error = 49 με

2/ A33972 [με] = 1.1*A33800 [με] - 43
$R^2 = 0.972$
Standard Error = 64 με

3/ A33972 [με] = 0.93*A33800 [με] - 388
$R^2 = 0.982$
Standard Error = 40 με

average
1,2 & 3/ A33972 [με] = 1.15*A33800 [με] - 43
$R^2 = 0.971$
Standard Error = 74 με

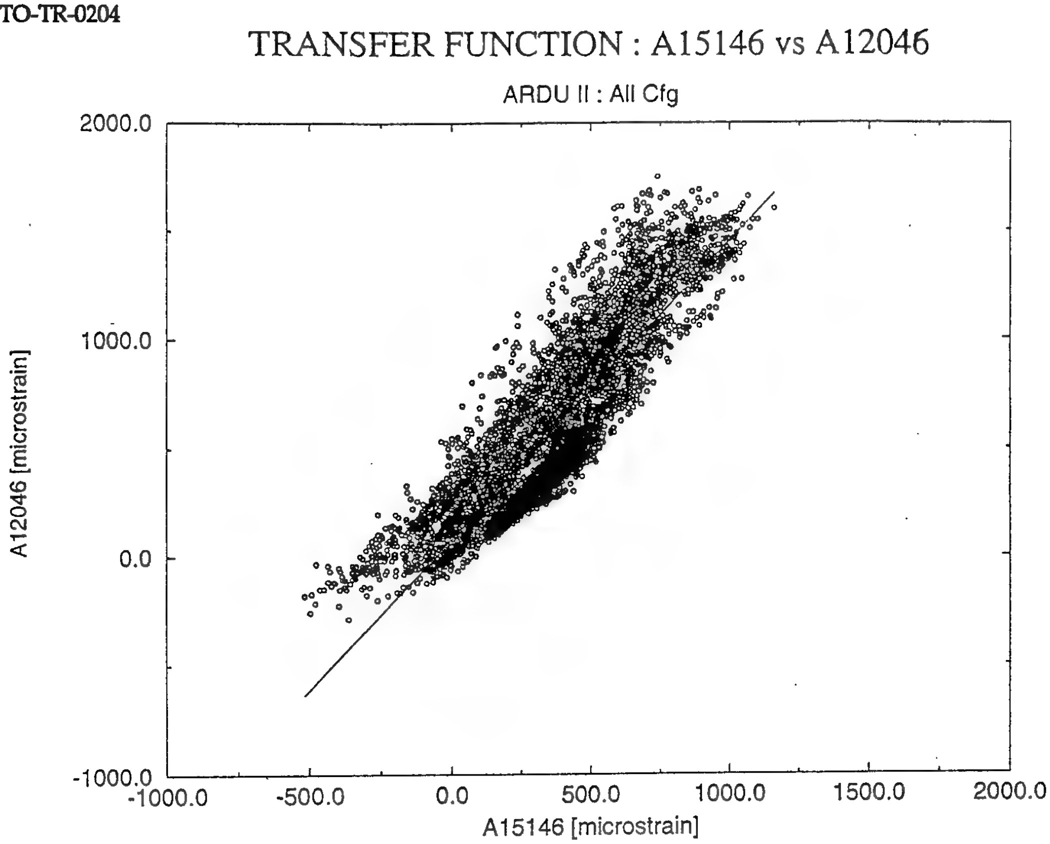

Figure A2.2: Channel 3 - 4 Transfer Function

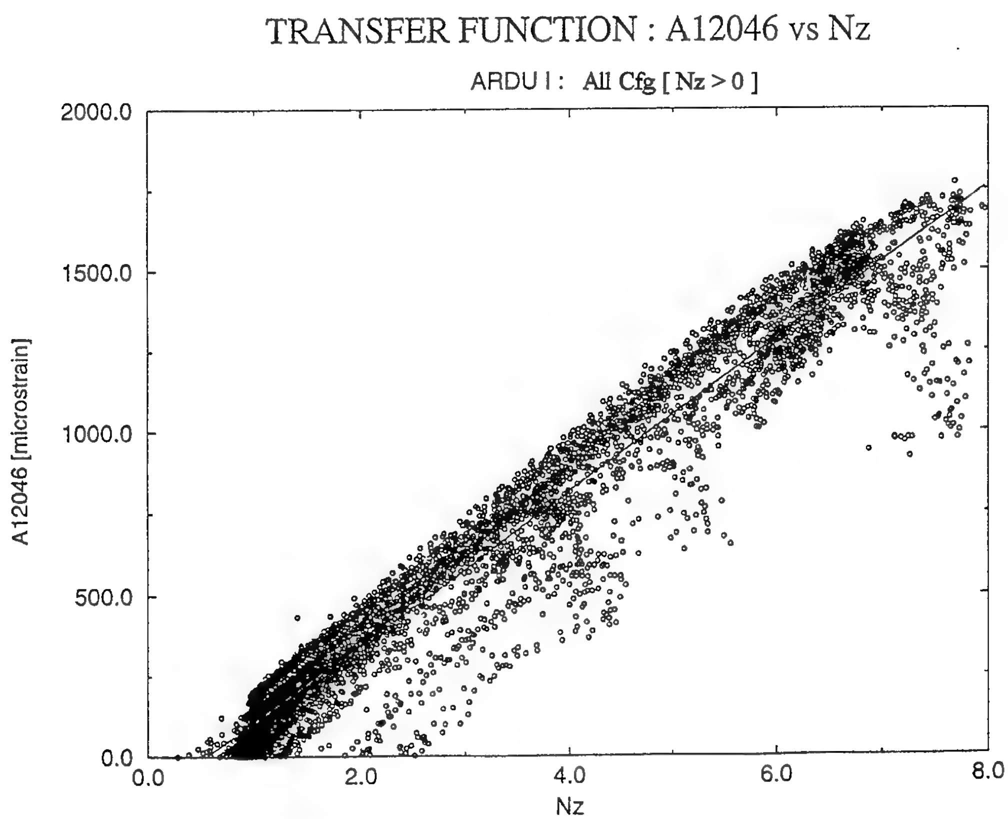

Figure A2.3: Channel 11 - 4 Transfer Function

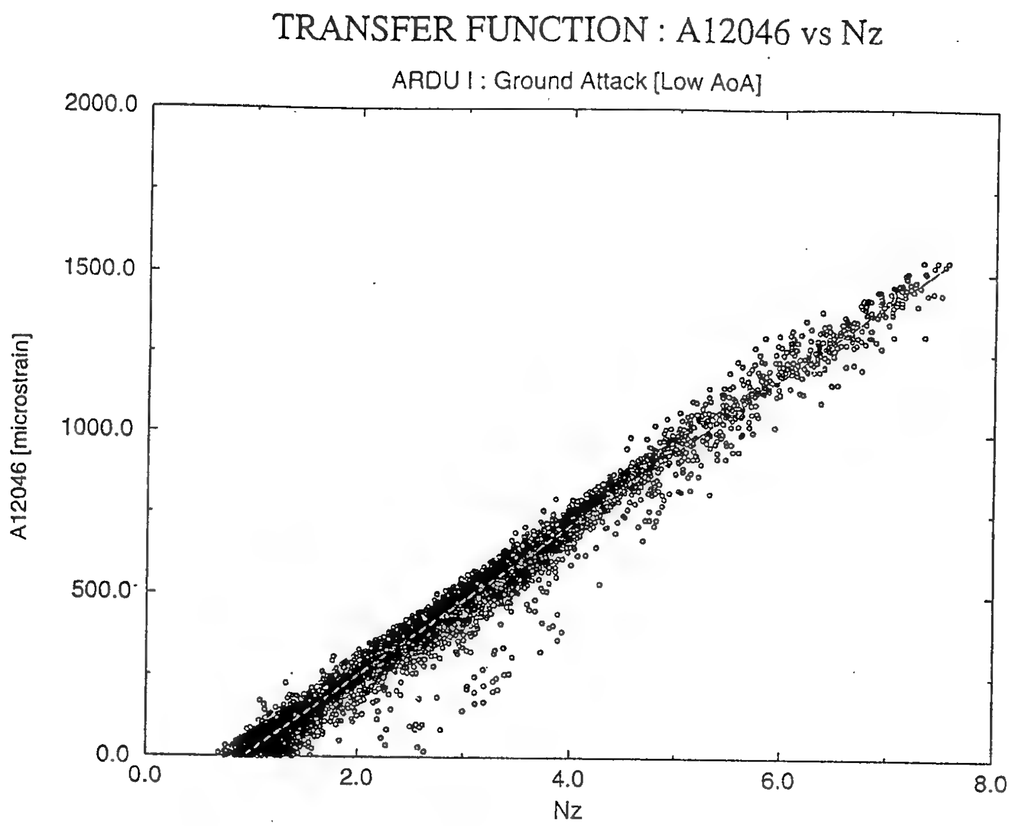

Figure A2.4: Channel 11 - 4 Transfer Function

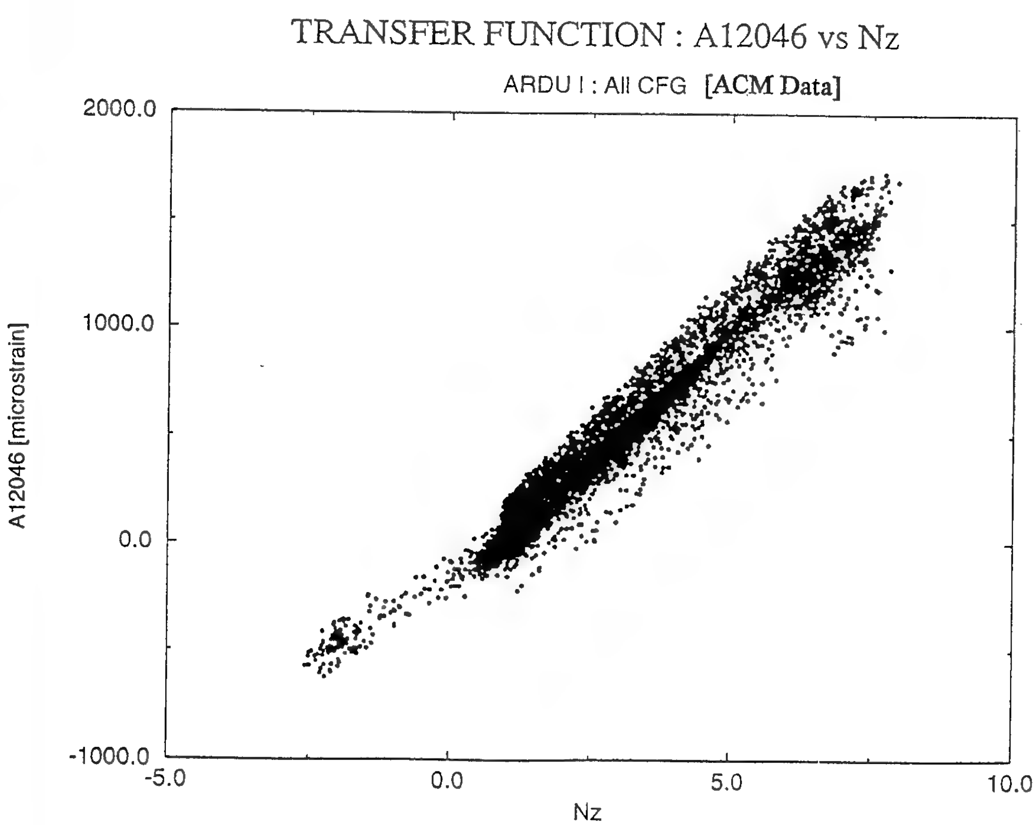

Figure A2.5: Channel 11 - 4 Transfer Function

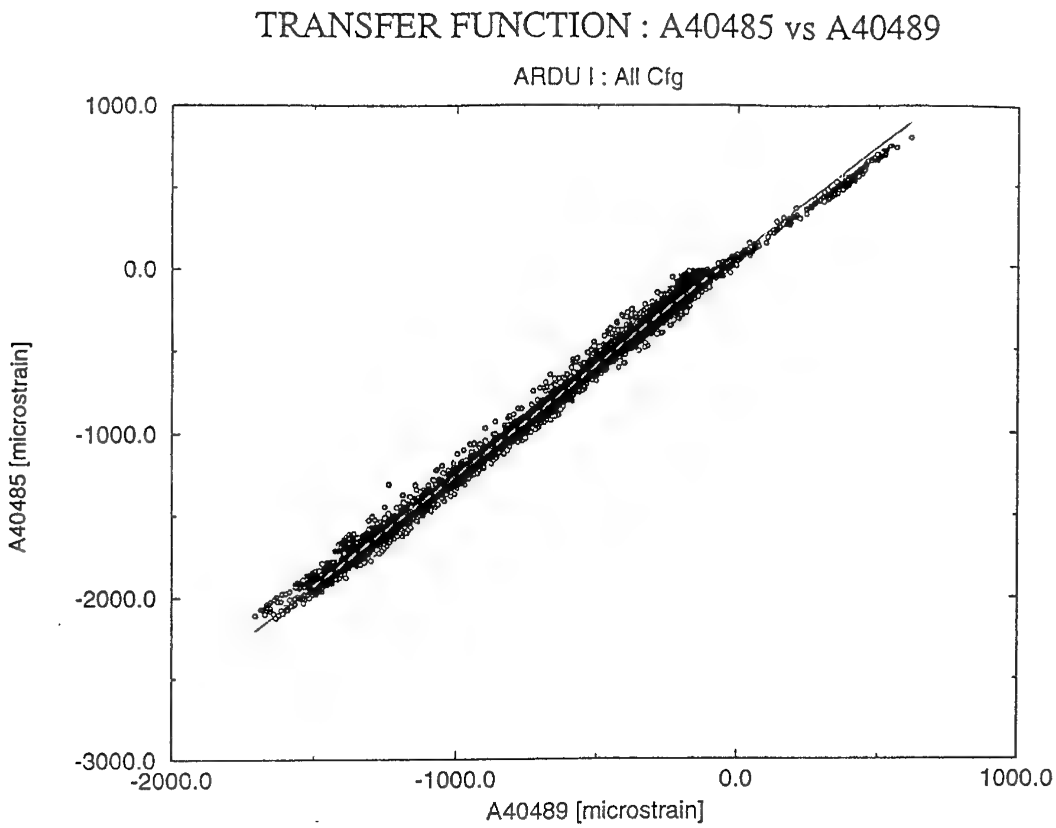

Figure A2.6: Channel 2 - 1 Transfer Function

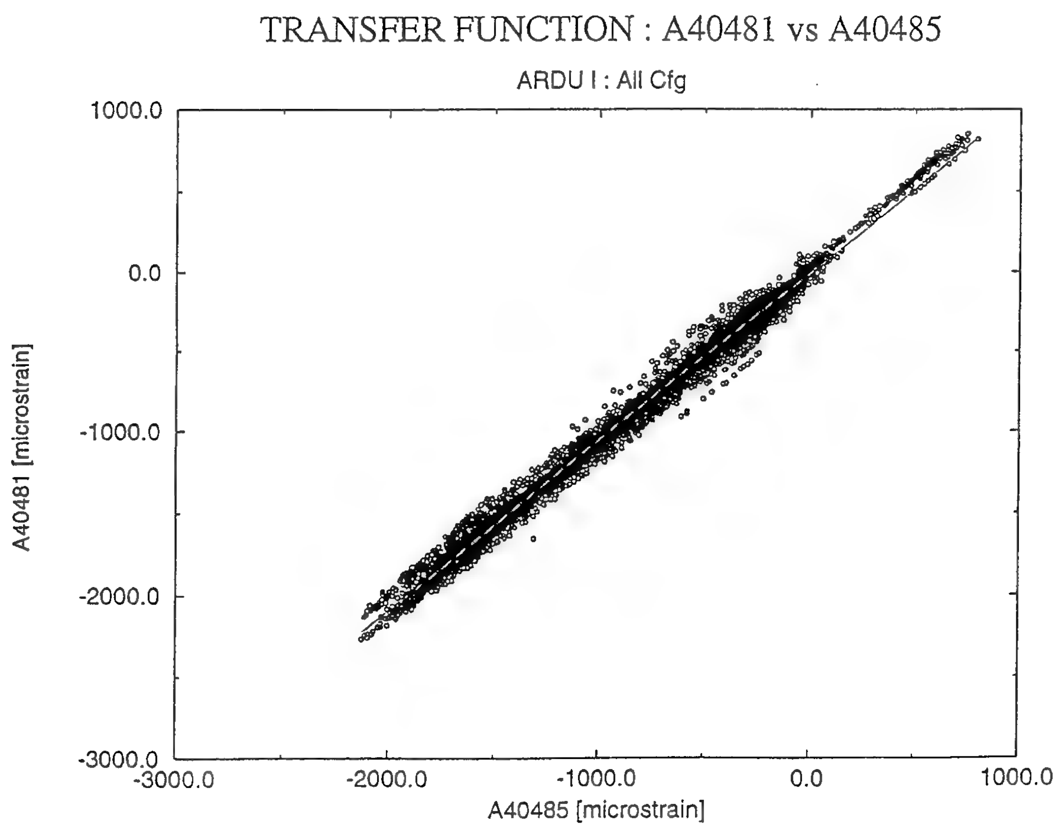

Figure A2.7: Channel 1 - 0 Transfer Function

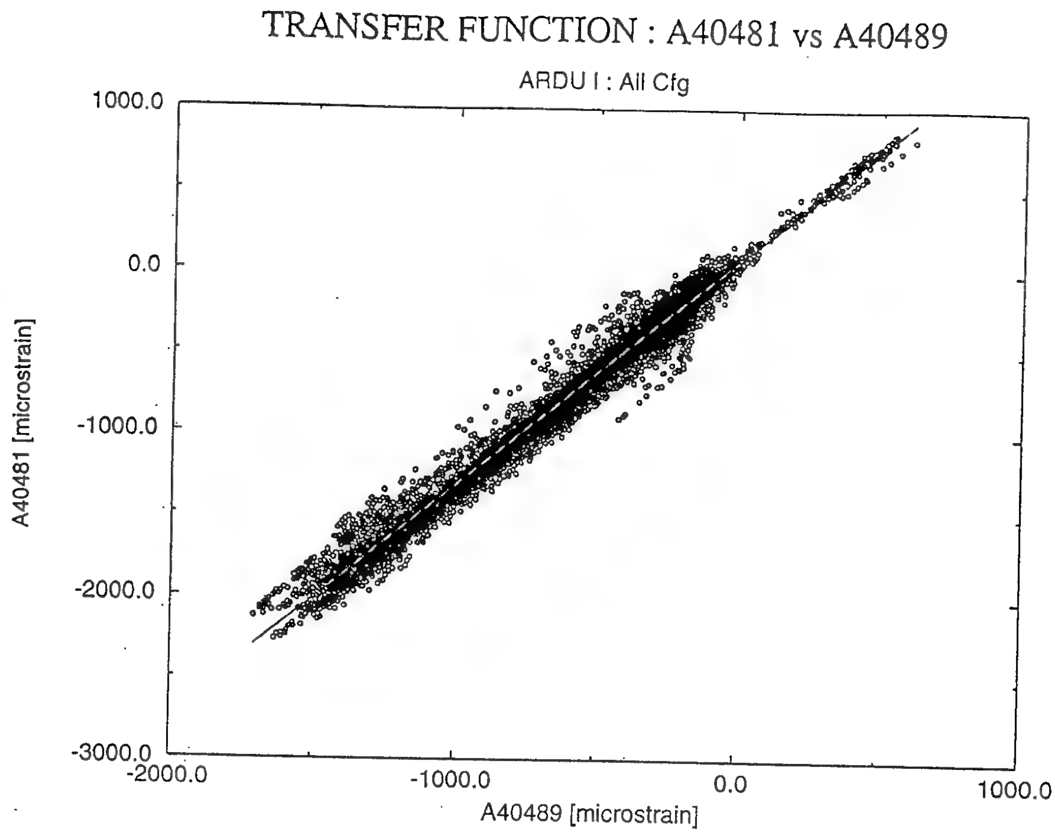

Figure A2.8: Channel 2 - 0 Transfer Function

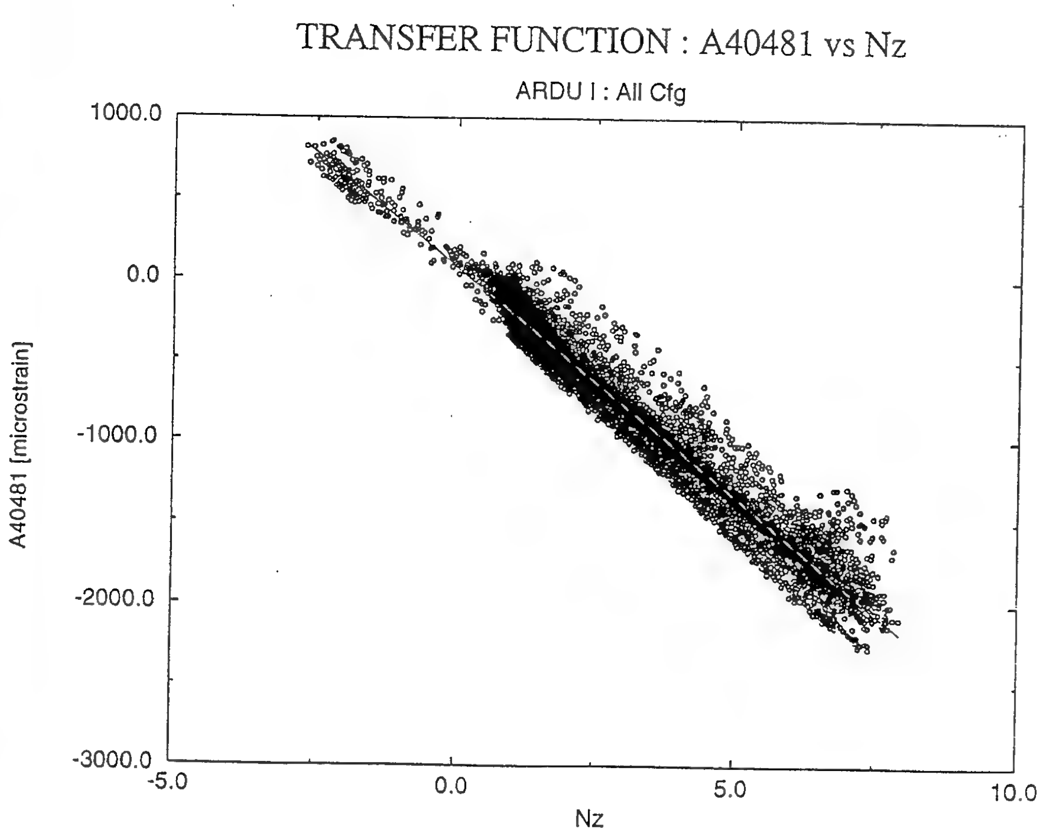

Figure A2.9: Channel 11 - 0 Transfer Function

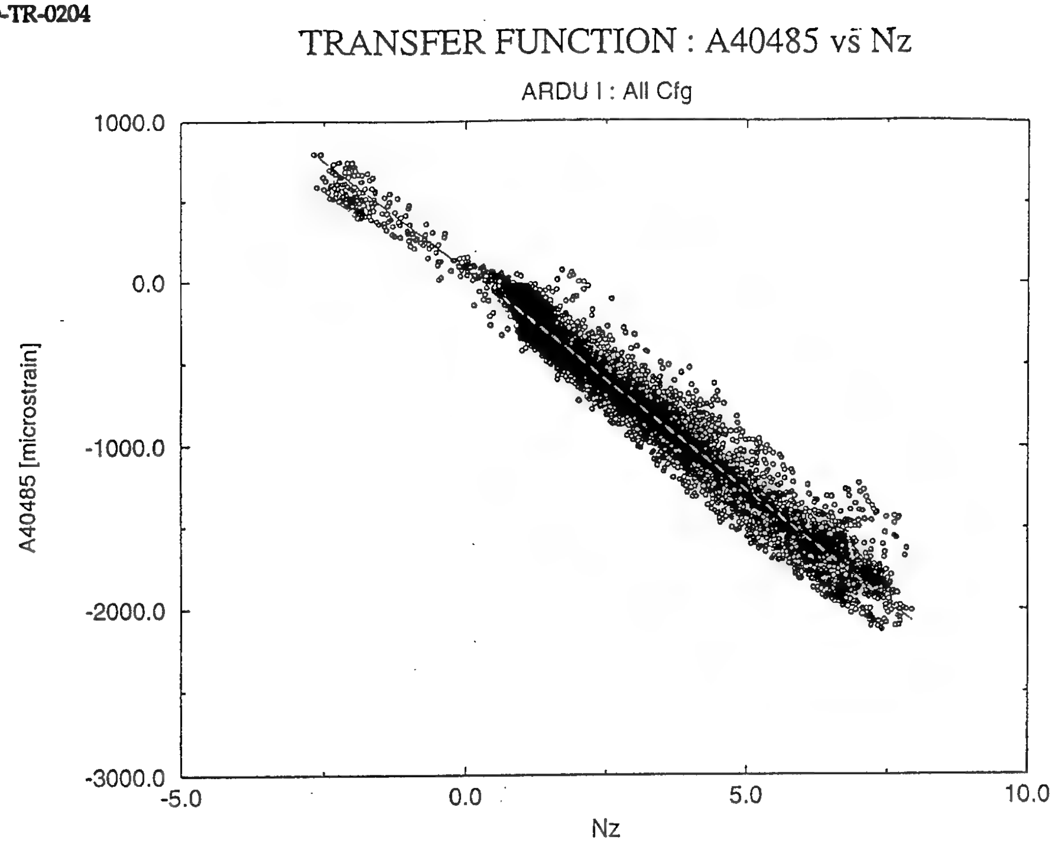

Figure A2.10: Channel 11 - 1 Transfer Function

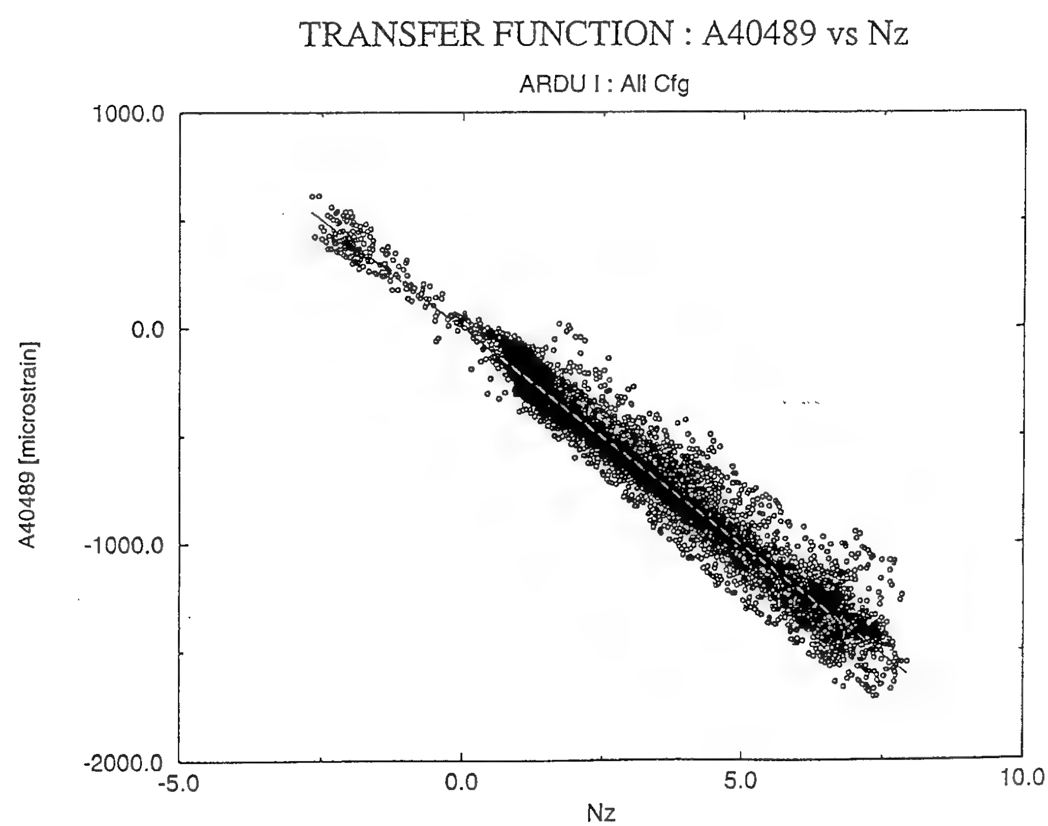

Figure A2.11: Channel 11 - 2 Transfer Function

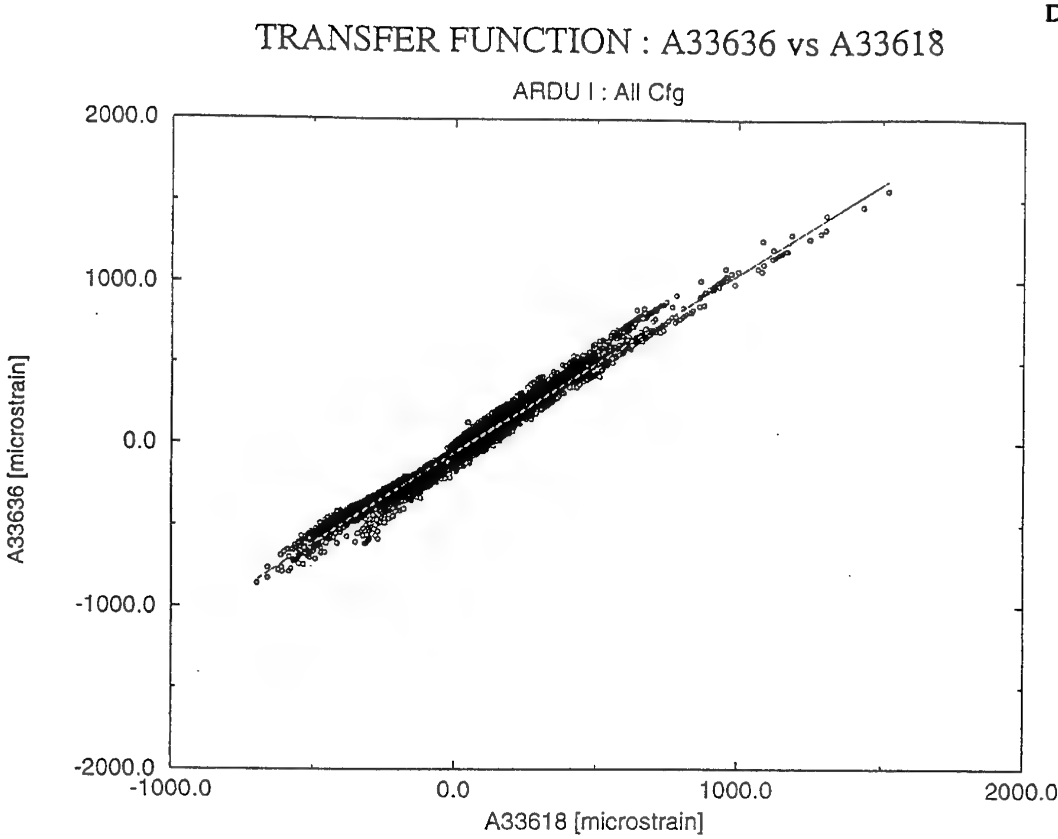

Figure A2.12: Channel 6 - 7 Transfer Function

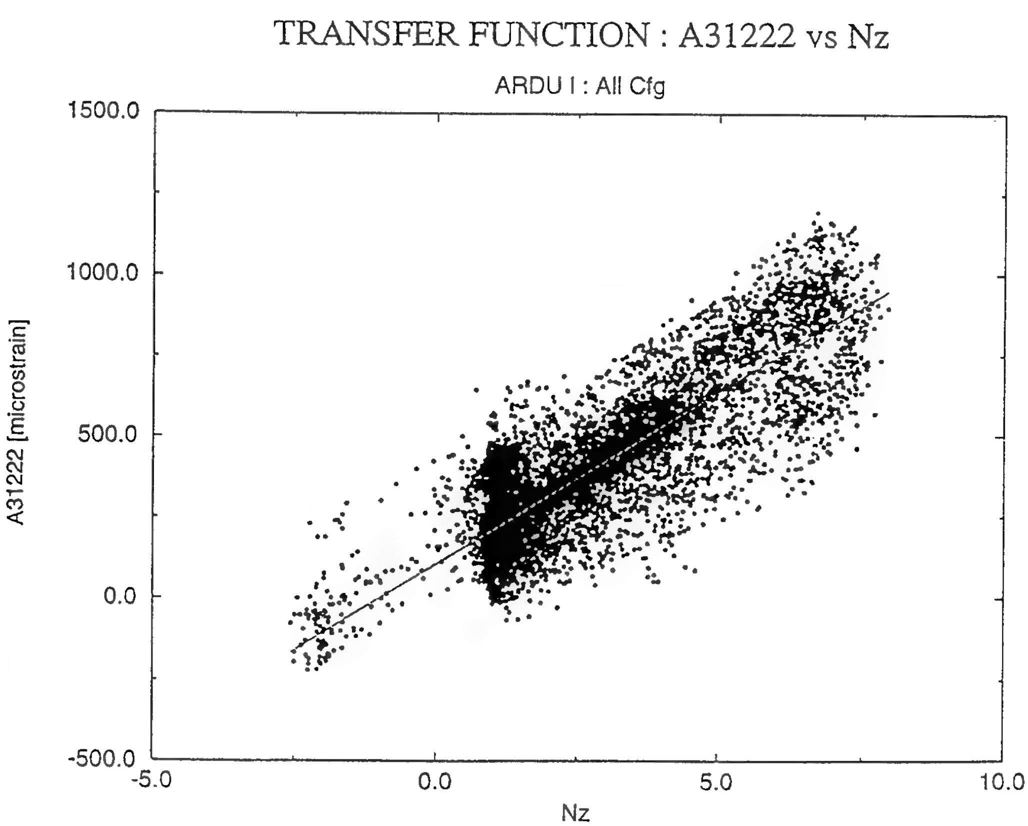

Figure A2.13: Channel 11 - 5 Transfer Function

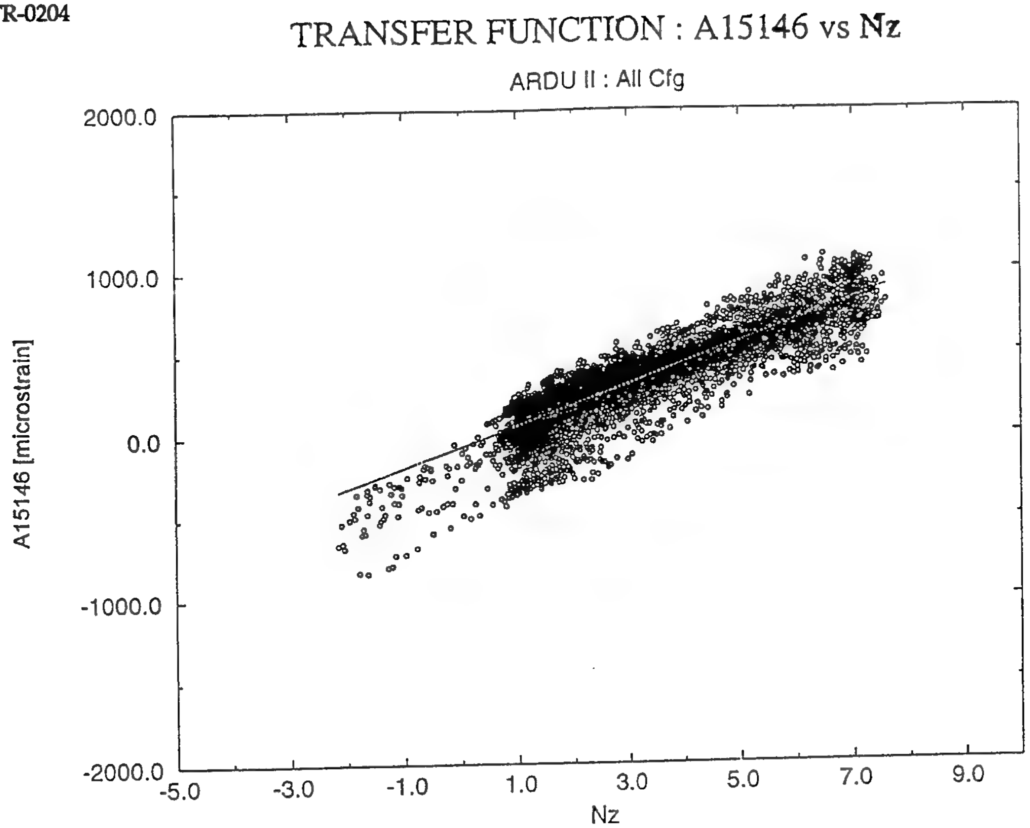

Figure A2.14: Channel 11 - 3 Transfer Function

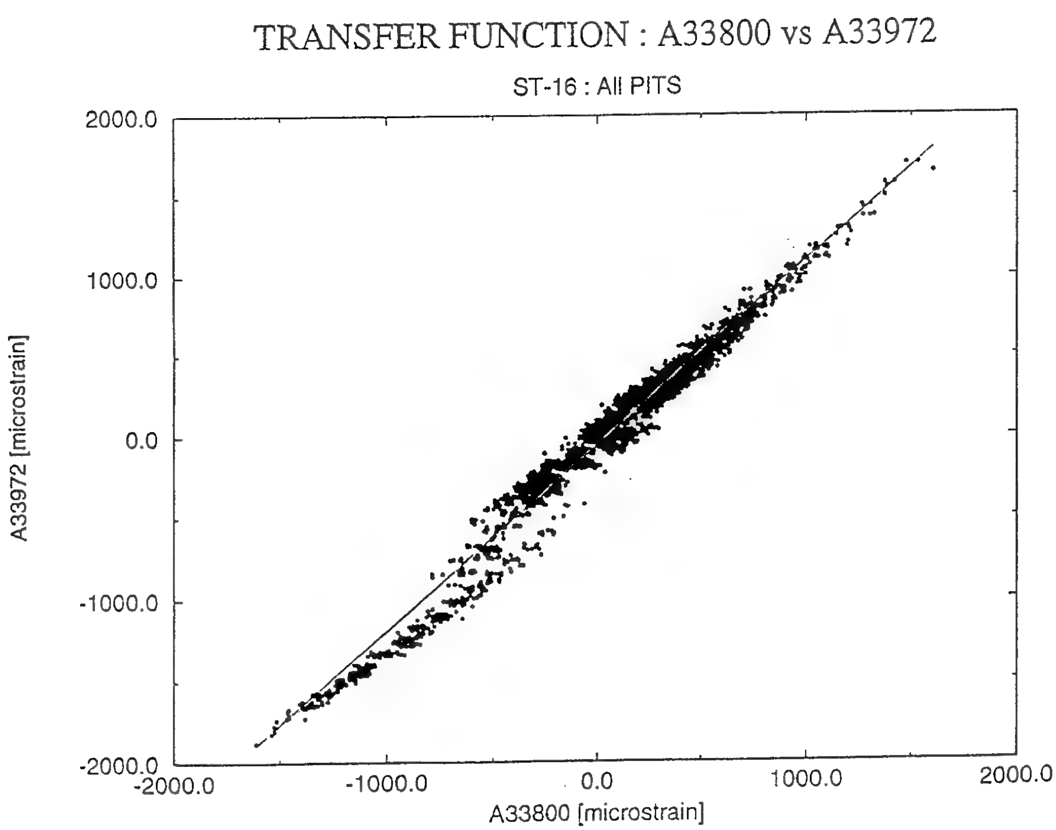

Figure A2.15: Channel 8 - 9 Transfer Function

Appendix 3

" Mean, Peak and Trough " Test Output for the Sample Aircraft

Table A3.1: Mean Test for Sample Aircraft

AFDAS CHANNELS

0	Y453	[BLKHD]	6	Y645	[HSTAB]
1	Y470	[BLKHD]	7	Y657	[HSTAB]
2	Y488	[BLKHD]	8	Y566	[VTAIL]
3	RHWF	[WFOLD]	9	Y598	[VTAIL]
4	RHWR	[WROOT]	10	RH	[WTEF]
5	Y213	[FF]	11	Nz	[@CG]

MEAN METHOD :

	Aircraft :	A21-17	A21-17	A21-26	A21-38	A21-38	A21-44	A21-44	A21-107	A21-117
	File :	M93354155	M93302141	M93342099	M93334236	M93305211	M93335158	M93302132	M93343091	M93342091
	TOF :	300	300	600	300	300	300	300	500/900	600
	FLT hrs :	27.7	5.4	20.9	27	10	18.4	12	16.1	33.1
CH : X Y	ACTUAL	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE
3 - 4	1.38	2.1	2.29	1.78	2.53	2.71	2.01	2.36	2.12	2.15
11 - 4	230	1064	599	476	580	520	581	575	673	540
2 - 1	1.33	1.01	0.93	1.08	1.17	1.5	1.01	1.02	0.94	1.14
1 - 0	1.04	1.02	1.05	0.67	1.32	1.26	1.36	1.04	0.73	1.14
2 - 0	1.39	1.02	1.01	0.74	1.66	1.85	1.42	1.1	0.73	1.32
11 - 0	-283	-872	-566	-258	-613	-557	-649	-531	-440	-528
11 - 1	-271	-715	-379	-347	-415	-356	-441	-389	-547	-446
11 - 2	-202	-821	-573	-336	-373	-293	-490	-483	-617	-394
6 - 7	1.1	1.38	1.33	1.29	0.99	1.34	1.22	1.34	0.81	2.01
11 - 5	105	162	88	265	190	-	-	-	-	-
11 - 3	130	481	243	265	203	198	284	230	310	247
9 - 8	1.15	0.95	0.83	0.8	0.87	0.4	1.24	1.02	0.33	0.68

Table A3.2: Peak Test for Sample Aircraft

AFDAS CHANNELS

0	Y453	[BLKHD]	**6**	Y645	[HSTAB]
1	Y470	[BLKHD]	**7**	Y657	[HSTAB]
2	Y488	[BLKHD]	**8**	Y566	[VTAIL]
3	RHWF	[WFOLD]	**9**	Y598	[VTAIL]
4	RHWR	[WROOT]	**10**	RH	[WTEF]
5	Y213	[FF]	**11**	Nz	[@ CG]

PEAK METHOD :

Aircraft :		**A21-17**	**A21-17**	**A21-26**	**A21-38**	**A21-38**	**A21-44**	**A21-44**	**A21-107**	**A21-117**
File :		M93354155	M93302141	M93342099	M93334236	M93305211	M93335158	M93302132	M93343091	M93342091
TOF :		300	300	600	300	300	300	300	500/900	600
FLT hrs :		27.7	5.4	20.9	27	10	18.4	12	16.1	33.1
CH : X Y	ACTUAL	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE
3 - 4	1.38	1.99	2.15	1.72	2.17	2.31	1.91	2.19	2.04	2.25
11 - 4	230	443	450	355	439	423	444	432	494	414
2 - 1	1.33	0.97	0.94	1.02	1.16	1.37	0.97	0.98	0.92	1.15
1 - 0	1.04	0.99	1.08	0.71	1.37	1.31	1.4	1.05	0.68	1.15
2 - 0	1.39	0.95	1.04	0.79	1.64	1.83	1.4	1.13	0.71	1.34
11 - 0	-283	-603	-530	-236	-535	-514	-579	-498	-360	-470
11 - 1	-271	-519	-466	-318	-408	-413	-457	-409	-428	-357
11 - 2	-202	-366	-472	-286	-337	-306	-443	-389	-471	-365
6 - 7	1.1	0.92	1.11	1.24	1.04	1.26	1.08	1.19	1.98	1.28
11 - 5	105	101	117	196	174	-	-	-	-	-
11 - 3	130	197	215	200	198	180	247	189	238	176
9 - 8	1.15	0.69	0.73	0.88	0.8	0.72	0.74	0.65	0.79	0.76

Table A3.3: Trough Test for Sample Aircraft

AFDAS CHANNELS

0	Y453	[BLKHD]	**6**	Y645	[HSTAB]
1	Y470	[BLKHD]	**7**	Y657	[HSTAB]
2	Y488	[BLKHD]	**8**	Y566	[VTAIL]
3	RHWF	[WFOLD]	**9**	Y598	[VTAIL]
4	RHWR	[WROOT]	**10**	RH	[WTEF]
5	Y213	[FF]	**11**	Nz	[@CG]

TROUGH METHOD :

	Aircraft :	A21-17	A21-17	A21-26	A21-38	A21-38	A21-44	A21-44	A21-107	A21-117
	File :	M93354155	M93302141	M93342099	M93334236	M93305211	M93335158	M93302132	M93343091	M93342091
	TOF :	300	300	600	300	300	300	300	500/900	600
	FLT hrs :	27.7	5.4	20.9	27	10	18.4	12	16.1	33.1
CH : X Y	ACTUAL	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE	SLOPE
3 - 4	1.38	2.17	2.25	1.79	2.59	2.59	2.07	2.33	2.05	2.11
11 - 4	230	927	552	433	540	472	511	496	592	506
2 - 1	1.33	0.97	0.93	1.06	1.08	1.22	0.96	0.98	0.92	1.06
1 - 0	1.04	1.23	1.19	0.79	1.41	1.37	1.41	1.28	0.83	1.34
2 - 0	1.39	1.22	1.18	0.83	1.59	1.69	1.41	1.27	0.84	1.46
11 - 0	-283	-790	-556	-205	-603	-539	-610	-506	-390	-520
11 - 1	-271	-460	-454	-287	-453	-325	-440	-373	-433	-305
11 - 2	-202	-662	-526	-327	-369	-288	-434	-443	-558	-377
6 - 7	1.1	1.33	1.31	1.3	0.97	1.17	1.32	1.29	1.46	1.85
11 - 5	105	196	105	245	199	-	-	-	-	-
11 - 3	130	457	233	249	184	181	255	215	390	240
9 - 8	1.15	0.72	0.59	0.69	0.72	0.6	0.84	0.69	0.5	0.53

A Data Screening Technique for AFDAS

L. Molent, K. Walker and R.W. Ogden

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Aircraft Fatigue Data Analysis System Data validation

20. ABSTRACT

This report presents the details of a technique which was adapted to correlate two individual Aircraft Fatigue Data Analysis System (AFDAS) data channels, or other data presented as range mean pairs, as a method of data screening or validation. Although the technique is here-in demonstrated by using operational RAAF F/A-18 AFDAS data, the approach is not aircraft type dependent, and is intended for general AFDAS (or any range mean pair) data screening purposes. A PC based program developed to implement the screening process is also described.